LAMONT GEOLOGICAL OBSERVATORY
COLUMBIA UNIVERSITY
PALISADES, NEW YORK

PRECISION SOUND VELOCITY PROFILES IN THE OCEAN

VOLUME I

THE SOUND CHANNEL IN THE BERMUDA-BARBADOS REGION
November - December
(1963)

by

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ABSTRACT

A collection of high-precision detailed consecutive sound velocity - depth profiles of the sound channel in the ocean is presented from 17 Stations in the Bermuda - Barbados area for November and December 1963. The data is displayed both in the form of families of individual profiles, with time information; and as composite envelopes for each station, emphasizing the total spread at each site. A short description of the most salient features is given.

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INTRODUCTION

This report describes the sound channel in the Bermuda - Barbados area. It presents detailed, consecutive high precision sound velocity-depth profiles obtained at several stations in this area in the months of November and December 1963, on cruise 99 of our R/V SIR HORACE LAMB.

The cruise of the SIR HORACE LAMB, on which these data were obtained, was planned to yield information about three kinds of variability in the sound channel:

(1) Short term variations at the same site. For this purpose, repeated consecutive profiles were taken at each station.

(2) Long term variations at the same site: Stations repeated at the same site at longer intervals, of the order of weeks.

(3) Dependence of the structure of the sound channel on geographical location: Stations a short time apart, a day or so, at different sites.

This report and the profiles are intended primarily as source material and as an illustration of the variability in the sound channel region. Therefore, no analysis or biography and hardly any discussion is included, except a barest outline.

INSTRUMENTATION

An outline of the instrumentation used has been presented elsewhere (Piip, 1964). In principle, two NBS-type veloci-

meters (two in order to have a constant check of one instrument against the other for any erratic behavior), a precision FM-output pressure gauge and an upside-down echosounder (pinger) were used in the submerged instrument package. This instrument package was suspended by means of a single-conductor armoured cable from the ship. During stations, the ship was hove to. Power to the instruments was fed down, and instrument signals were telemetered up over the same cable. The instruments were programmed to be read in the following repetitive sequence: pressure gauge, velocimeter 1, pressure gauge, velocimeter 2, and so on. The telemetered instrument output frequencies were counted and the results printed on paper tape, together with 10-minute time marks.

Winch speed for the profiles was controlled to give a complete instrument reading sequence about every 10 meters, or a sampling length for each instrument of about 2 meters in depth.

The pressure gauge was periodically checked against the pinger.

DATA PROCESSING

Data reduction was performed by computer. The velocimeter and pressure gauge readings were validated and converted to velocities in meters per second (m/s) and depths in meters (m). For each velocimeter reading, the average depth from the two pressure gauge readings immediately before and after was assigned. The velocity and depth values thus obtained were plotted on a CalComp plotter.

The final plots, as included in this report, were ob-

tained as a visual average of the two nearly coincident traces of the computer output. Only these profiles were used where the two velocimeter traces were tracking and in close agreement.

The programming, computerwork and plotting were done by Kenneth R. Stewart of the Naval Research Laboratory, using the facilities of the Sonar Group at NRL.

ACCURACY AND CORRECTIONS TO THE PLOTS

The estimated accuracy of the sound velocities in the plots presented herewith is ±20 cm/sec, precision about ±10 cm/sec. The velocities given in the plots pertain to a velocimeter standardized for +10°C ambient temperature. In order to obtain the true sound velocity at other ambient temperatures, corrections have to be applied to the indicated reading, because of the thermal expansion of the instrument. The corrections are given in the following table.

$$\text{True sound velocity} = V_i + \text{Correction}$$

$$\text{Correction} = 1.46 \cdot 10^{-5}(T - 10) \cdot V_i$$

where T - ambient temperature, °C.
V_i- indicated sound velocity.

T, °C	Correction, m/s
25	+0.33
20	+0.22
15	+0.11
10	±0.00
5	-0.11
0	-0.22

These corrections may be based on average temperature profiles for the region and season.

The velocimeters were standardized for +10°C, instead of 0°C, since this temperature is approximately in the middle of the range encountered in most non-Polar seas.

The depths as given in this report are accurate to ±10 meters, and are equivalent to uncorrected acoustic depths for a 1463 m/s (4800 feet/s) machine. To obtain true depths with sufficient accuracy, the indicated depths should be increased by 3% (Matthews,1944).

EXPLANATION OF PLOTS

The profiles are presented twice, in two forms:

Firstly: for each station, consecutive profiles are shown. The profiles have been separated by 2 m/s, to improve legibility. Each profile is identified by its number, and carries a mark to indicate a reference velocity of 1495 m/s (and 1490 m/s, when needed). The profiles are also provided with time information: the small 3-digit numbers connected by short horizontal lines to the profiles are 10 minute time ticks with the final zero omitted: thus 175 means 1750 GMT.

For Station 3 a pair of constant depth recordings, of several hours duration each, is included.

Secondly: composite envelopes for each station, with a note giving the total duration and number of the profiles. These envelopes indicate the maximum spread of sound velocities as a function of depth at each station. They are useful in identification of regions of particular instability.

The profiles and profile families are filed in geographical order, moving South. Stations near to each other are grouped together.

It should be noted that although the ship was hove to at each station, it was not anchored nor was it attempted to control its drift. In most cases the drift rate was of the order of 1 - $1\frac{1}{2}$ knots. Thus, the stations are not really measurements at a point, but represent a short section of the waters, both in time and space.

The positions as given are average positions during each station, as determined by usual navigation methods.

HIGHLIGHTS OF RESULTS

The general shape of the profiles obtained at different stations indicates that there are two regions of entirely different character in the sound channel while one goes south of Bermuda towards the Antilles.

North of 20°N we have a reasonably open, undisturbed sea. The profiles are rounded and "classical" in shape. The axis velocity is approximately 1492 m/s, axis depth 1100-1200 meters near Bermuda, decreasing to about 900-1000 meters at the Southern end of this region. The sound channel is relatively stable.

One station in this region, No. 3, shows an interesting development of a high-velocity bulge centered at 1000 meters depth. The station starts with quite smooth profiles (#1, 2). A few hours later, at depths between 900 and 1300 m, the profiles are indented towards the right, the high-velocity side. The last profile of the station seems to be on its way to becoming normal again. We were lucky in having the only good "constant depth" recordings of the cruise between profiles 2 and 3 of this station, at 945 m depth, and between 5 and 6,

at 935m. The gradual increase in sound velocity between 2 and 3, and subsequent decrease between 5 and 6, is well documented in these constant depth recordings. The bulge must be caused by a fairly large, 250 m thick cell of strange water moving in and gradually disappearing again. The motion of the cell is accompanied by large oscillations.

The region south of 20°N shows an entirely different character. The profiles are extremely jagged, strongly layered and very unstable. The reason for this must be the proximity of the Antillean Islands and the influence of deep currents, possibly from Anegada and other passages. The sound channel in this region occurs in the sub-Antarctic intermediate water at approximately 750-900 meters depth (Defant,1961). The minimum velocity is in the high 1480's, less than 1490 m/s. The channel is narrow close to the islands, as a result of the sub-Antarctic water hugging the coastline of the island arc, and broadens towards a more rounded shape when one moves east, towards the open Atlantic.

Stations 5, 9 and 15 show an extreme degree of instability. This station seems to be in a region where the most violent mixing occurs between the Caribbean and the sub-Antarctic waters.

Stations 6-8 have the highest axis velocities in this region. It seems as if at this location we find a deep patch of warmer or more saline water between the sub-Antarctic waters to the west and the normal Atlantic to the east of it. A comparison between Stations 6 and 8 is rather startling: These stations are less than 20 miles and a week apart, but the channel, and particularly the region just above the channel, looks

entirely different. In Station 6 it is very jagged and broad and unstable, in Station 8 it is behaving much better. This might be due to movements of the postulated high-velocity water mass in this region - it is probably a transient phenomenon.

A rather interesting feature of Stations 13, 13A, 12, 11 and 10 is the higher velocity notch in the profiles at around 1000 m depth. The notches are very prominent at Station 13, in the St. Lucia-Martinique Passage and get less and less distinct the further southeast one moves. These notches are probably caused by a deep, thin, easterly countercurrent from the St. Lucia-Martinique Passage which continues in a jet-like fashion for several hundred miles before losing its identity. The sound velocities in the notches at different stations agree very closely with an isothermohaline water mass changing its depth. Assuming constant salinity in this layer, the sound velocity variations between Stations 13 and 11 can be explained by assuming a slight cooling of about 0.1°C of the water, in addition to changes in depth, in the course of its south-eastward motion.

COMPOSITE ENVELOPES

The composite profile envelopes indicate that there are regions of high and low variability in the ocean. In the "open" sea, the waters are more uniform and the total spread of profiles is smaller and more evenly distributed in depth than in areas close to currents and sources. The variations, both in time and space, become smaller the deeper one goes from the bottom of the deep thermocline. But there is no place in the

seas, at least at moderate depths and in the region covered by this report, where the waters are and stay uniform: in that case, all profiles (sound velocity or temperature), taken at different times, would be identical.

In any region, combining more and more individual profiles into a composite results in a gradual widening of the envelope, until a limit is reached: the total variability at that site. The saturation number of profiles, or the time spent on station, will depend on the site; it will be less in an open sea, greater in a disturbed area. (We have as yet not made any attempt to determine the optimum or most economical duration or number of profiles required).

DISCUSSION

An inspection of the individual profiles shown in Figures 2-19 shows that all profiles, even those taken one after another at the same site, are slightly different. This is due to the inhomogeneity of the oceanic waters, even at great depths and far from any sources - it seems as if large water masses, instead of mixing thoroughly during their long and slow journeys from the source, break up into layers and cells of moderate size. These "pieces" of water move about as discrete entities and stay this way for periods that must be measured in months, possibly years. (A cell that occurs in the middle of the ocean, a thousand miles from the closest possible source, must have been underway for at least a month, even if it had been moving at an average speed of a knot). Exchange processes between such discrete cells, which would tend to homogenize the oceans even in fine structure, must be very much slower and less effective than macroscopic mixing.

By "macroscopic mixing" we mean processes which bring the average properties, as contrasted to parameters at each point, to a homogeneous result.

A practical corollary of the instability and variability of deep waters is the problem of describing such a structure.

It has been, and still is common practice to give sound velocity-depth information for any location and time in the form of a profile, usually smooth, or values at selected depths. Information presented in this fashion can at best be only "typical", since it only pertains to one particular time and site. At other times, even a few hours from the station, the structure might be different. No information as to the stability at the station site can be imparted by one smooth profile, or values at selected depths. In several hydroacoustic applications, notably use of sofar signals for the precise location of missile impact positions, the knowledge of true sound velocity, or at least the spread of probable velocities, can be vital.

Therefore, it would be of great value if data (whether sound velocity, temperature, salinity or density) were presented whenever possible, either as a band or, numerically, as an average or most probable value plus-minus a spread, instead of a single curve or set of figures.

ACKNOWLEDGEMENTS

Thanks are due to Acoustics Programs, U.S. Office of Naval Research, under whose auspices this work was performed; to C.L. Buchanan of the U.S. Naval Research Laboratory, who made the computer facilities of the NRL SONAR group available to us; to

Kenneth R. Stewart, at that time also of NRL, who performed the arduous task of our data reduction on the computer; and to my colleagues and collaborators at the Columbia University Geophysical Field Station, whose aid has been invaluable in the success of this program: particularly Brian Turner, and the Master, Captain C. McCann and the crew of our R/V SIR HORACE LAMB.

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Matthews, D.J., 1944: "Tables of the Velocity of Sound in Pure Water and Sea Water". The Admiralty, London.

Piip, A.T., 1964: "Fine Structure and Stability of the Sound Channel in the Ocean", J. Acoust. Soc. Am. 36, 10, 1948-1953, October 1964.

LIST OF ILLUSTRATIONS AND STATIONS

continued

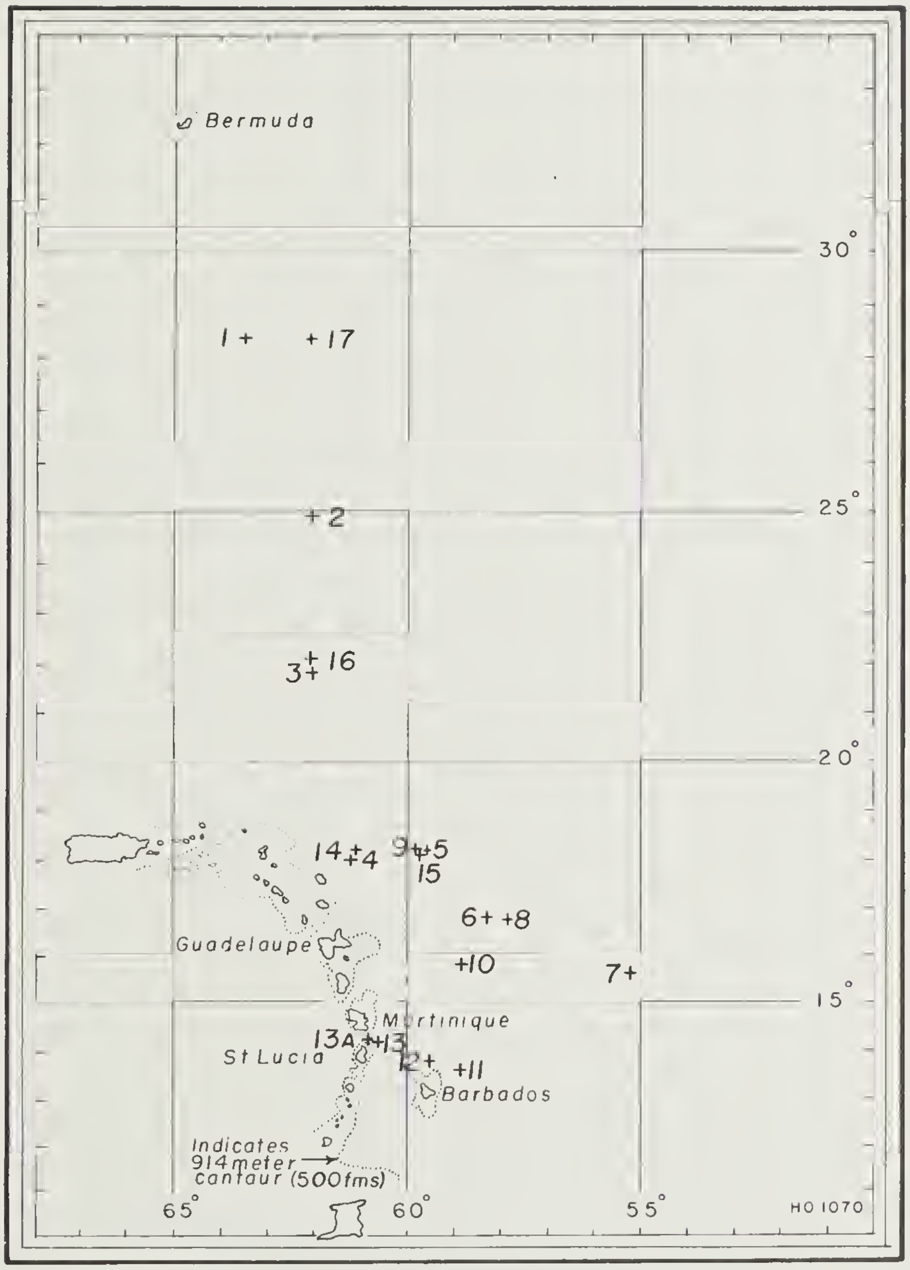


Fig. I Chart of Stations.

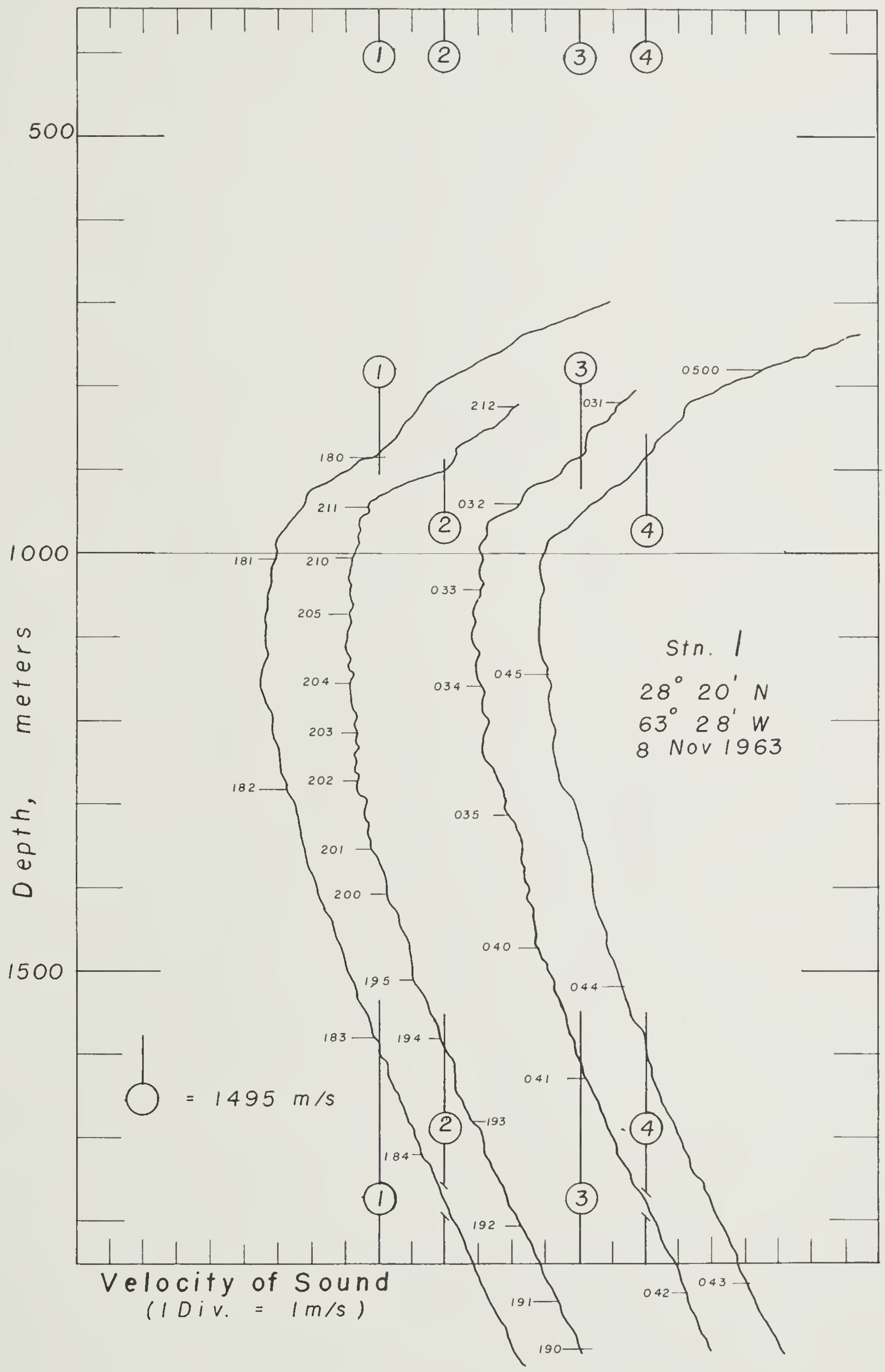
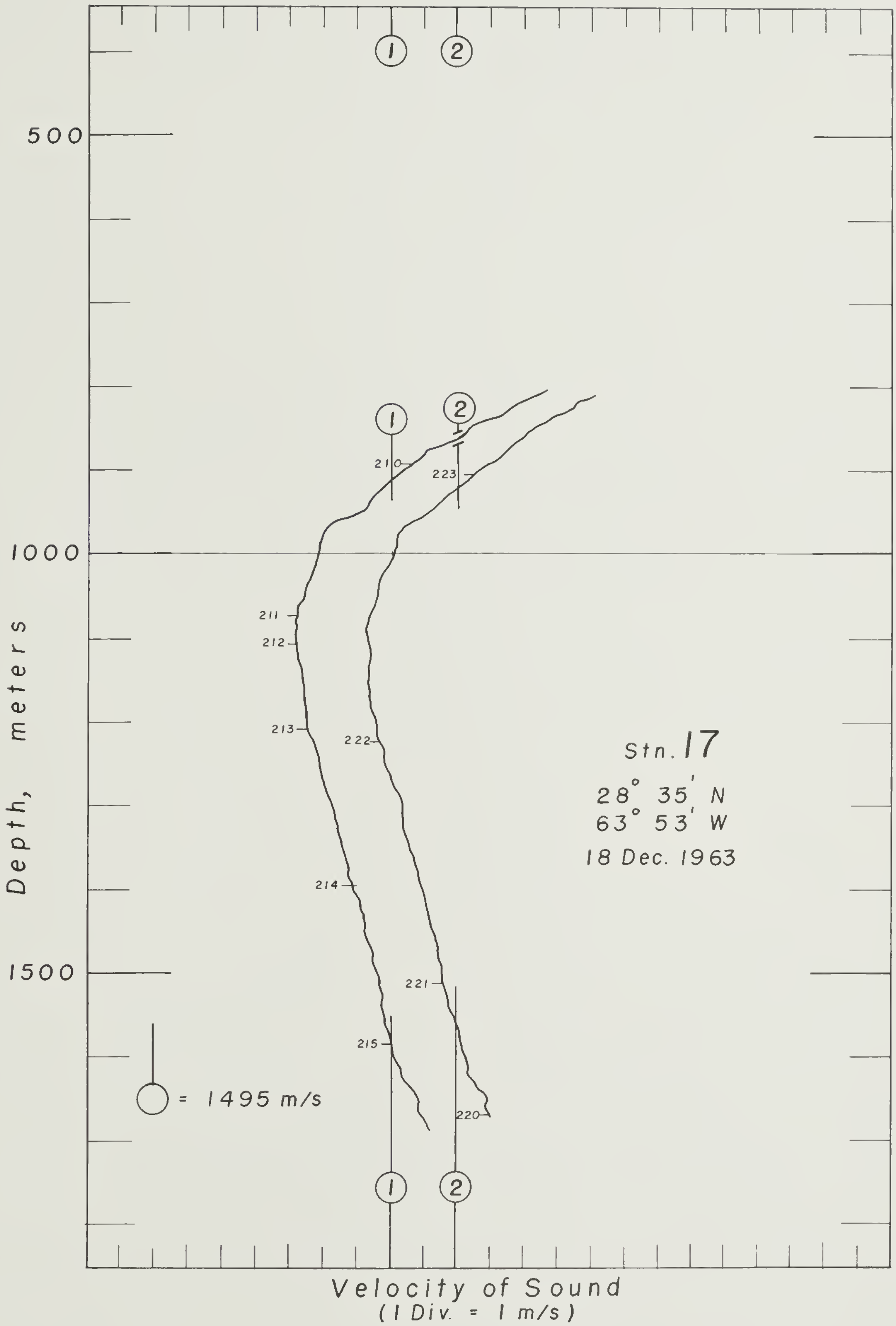


Fig. 2 Profile Family, Station I.



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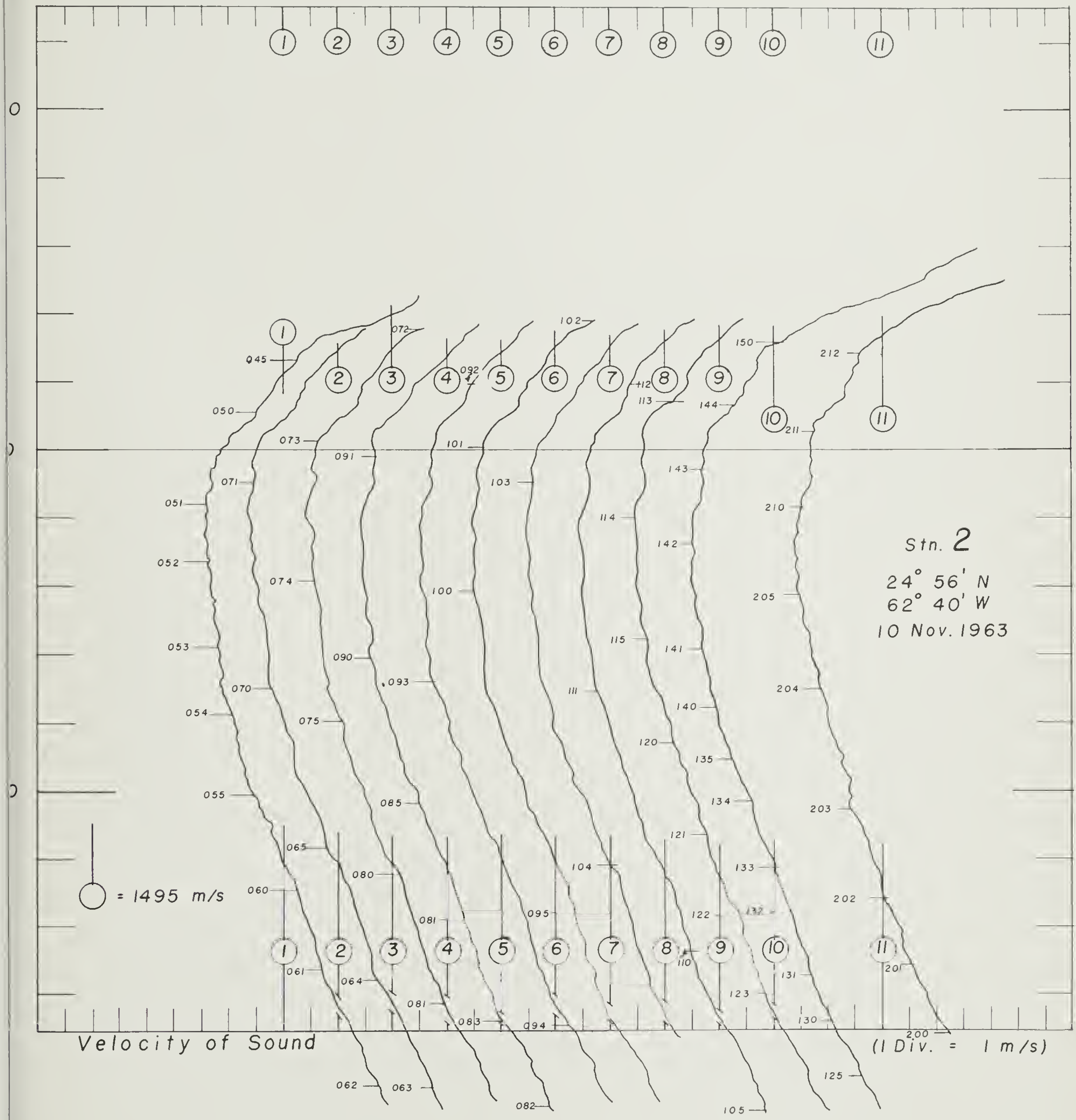

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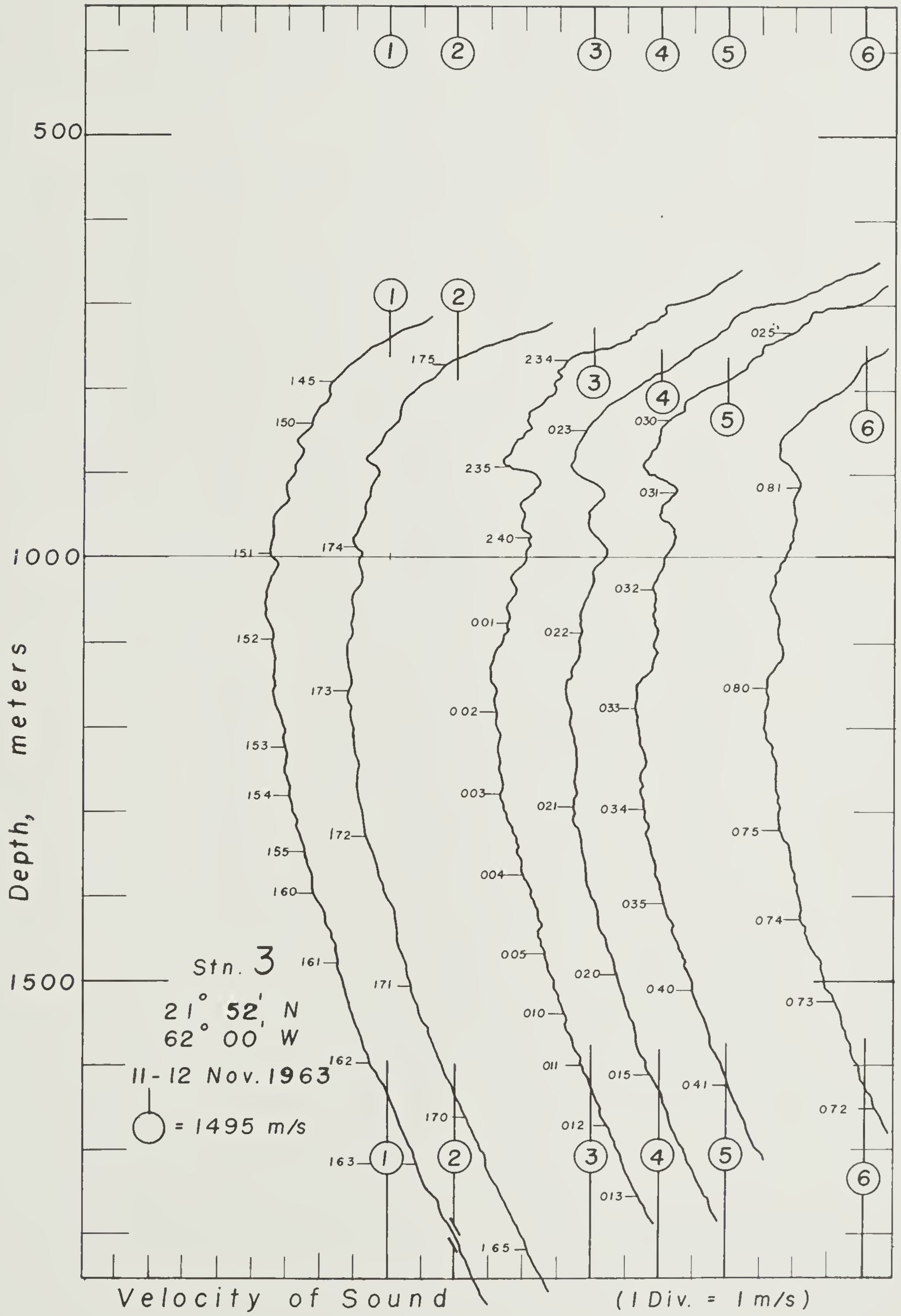

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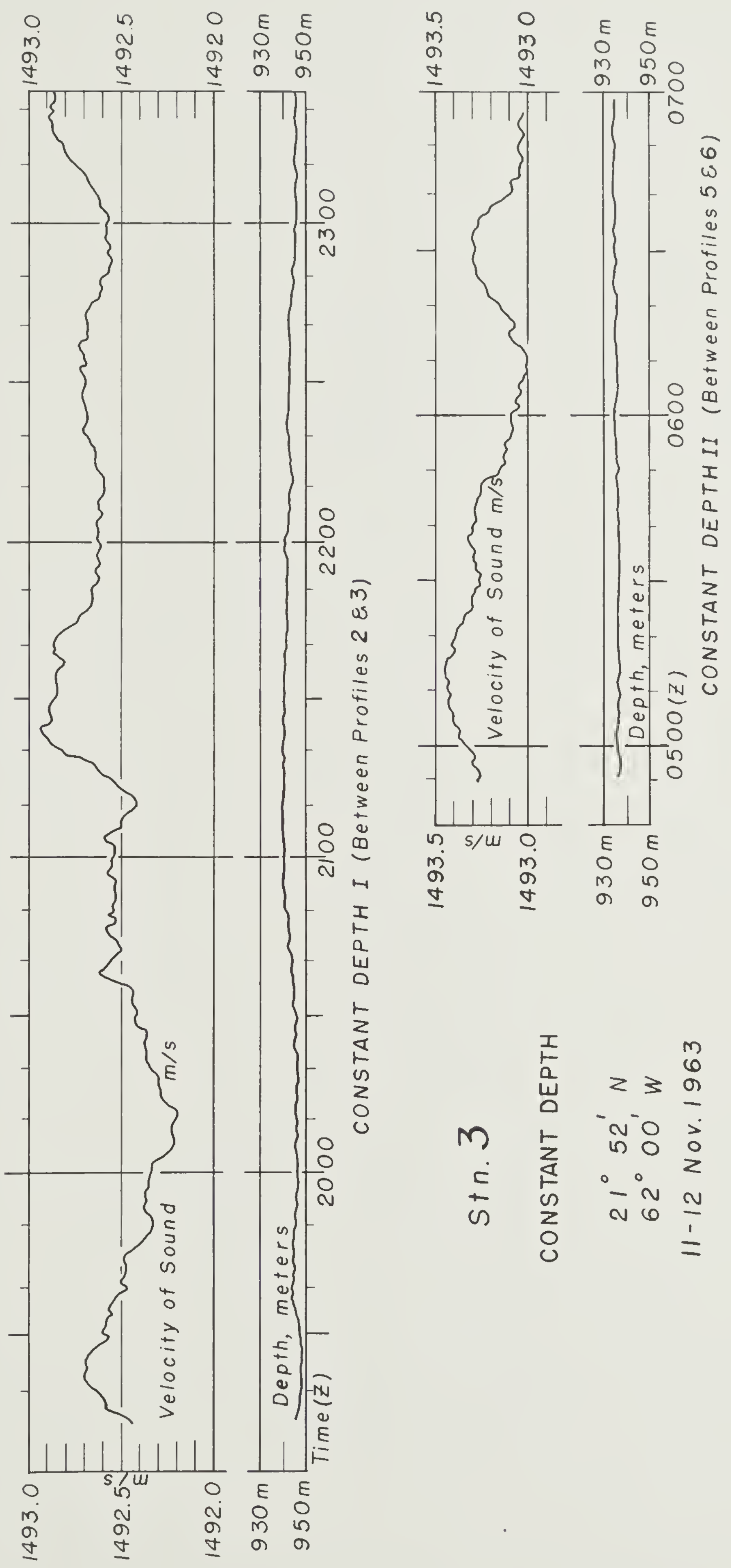

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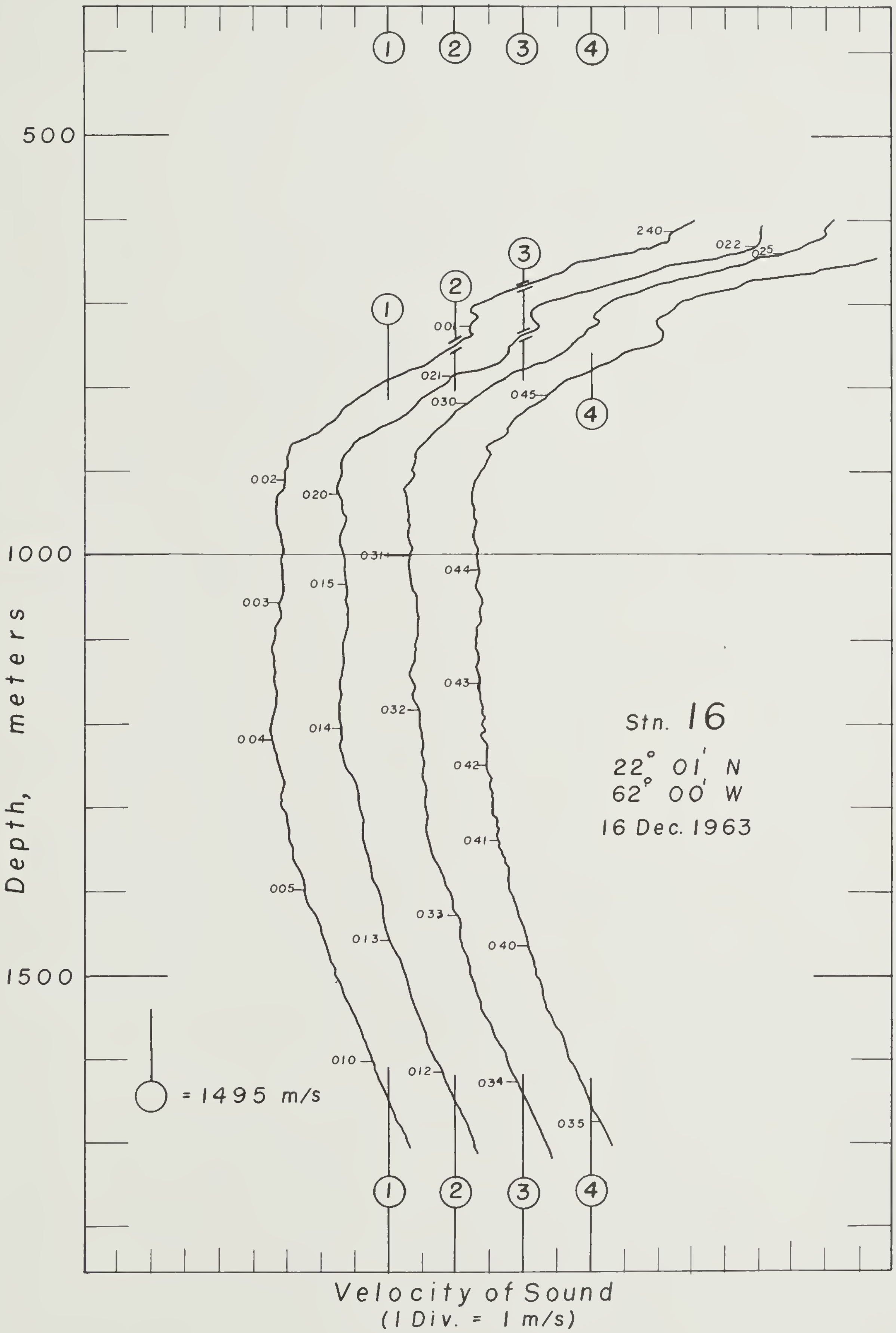
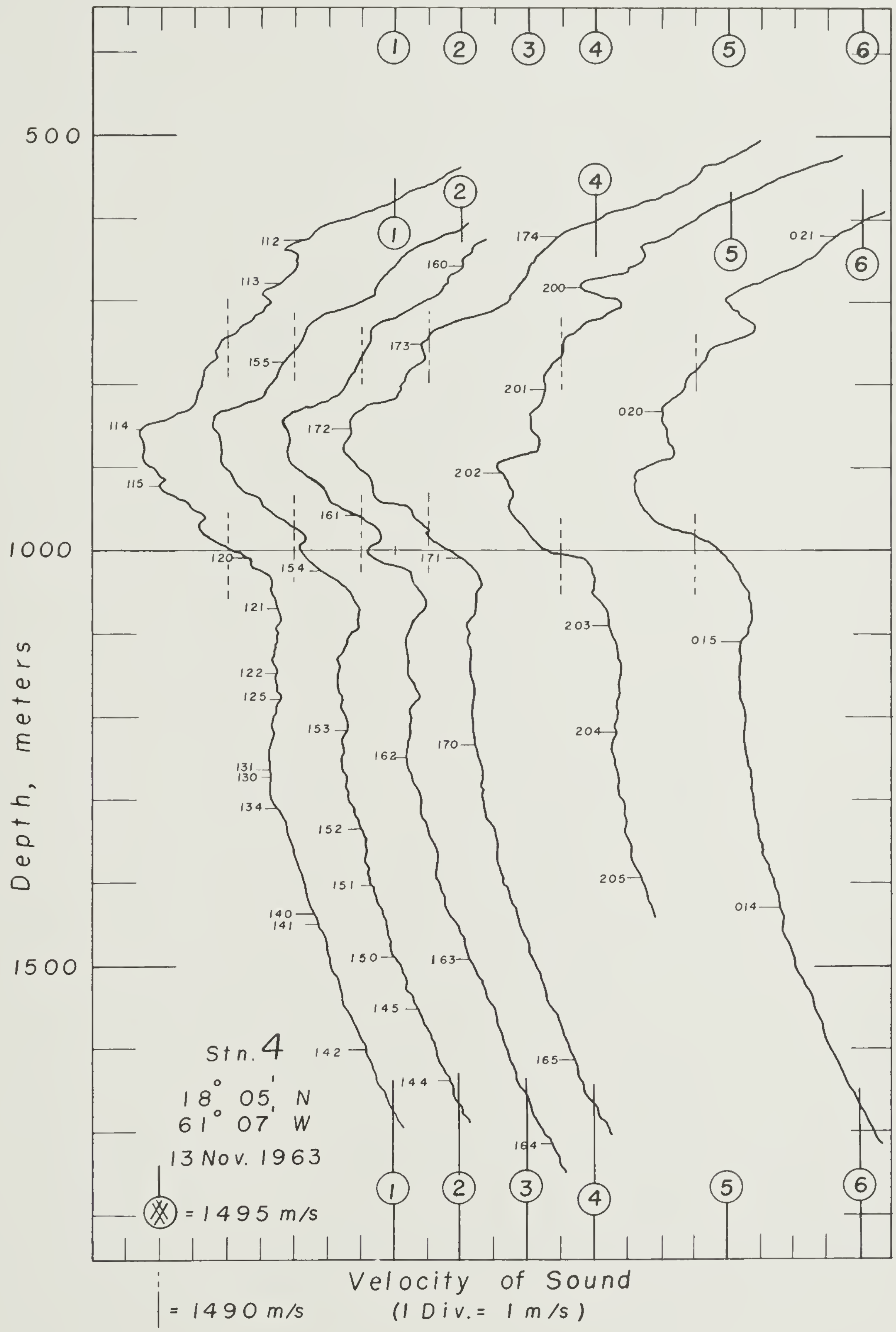


Fig. 7. Profile Family, Station 16.



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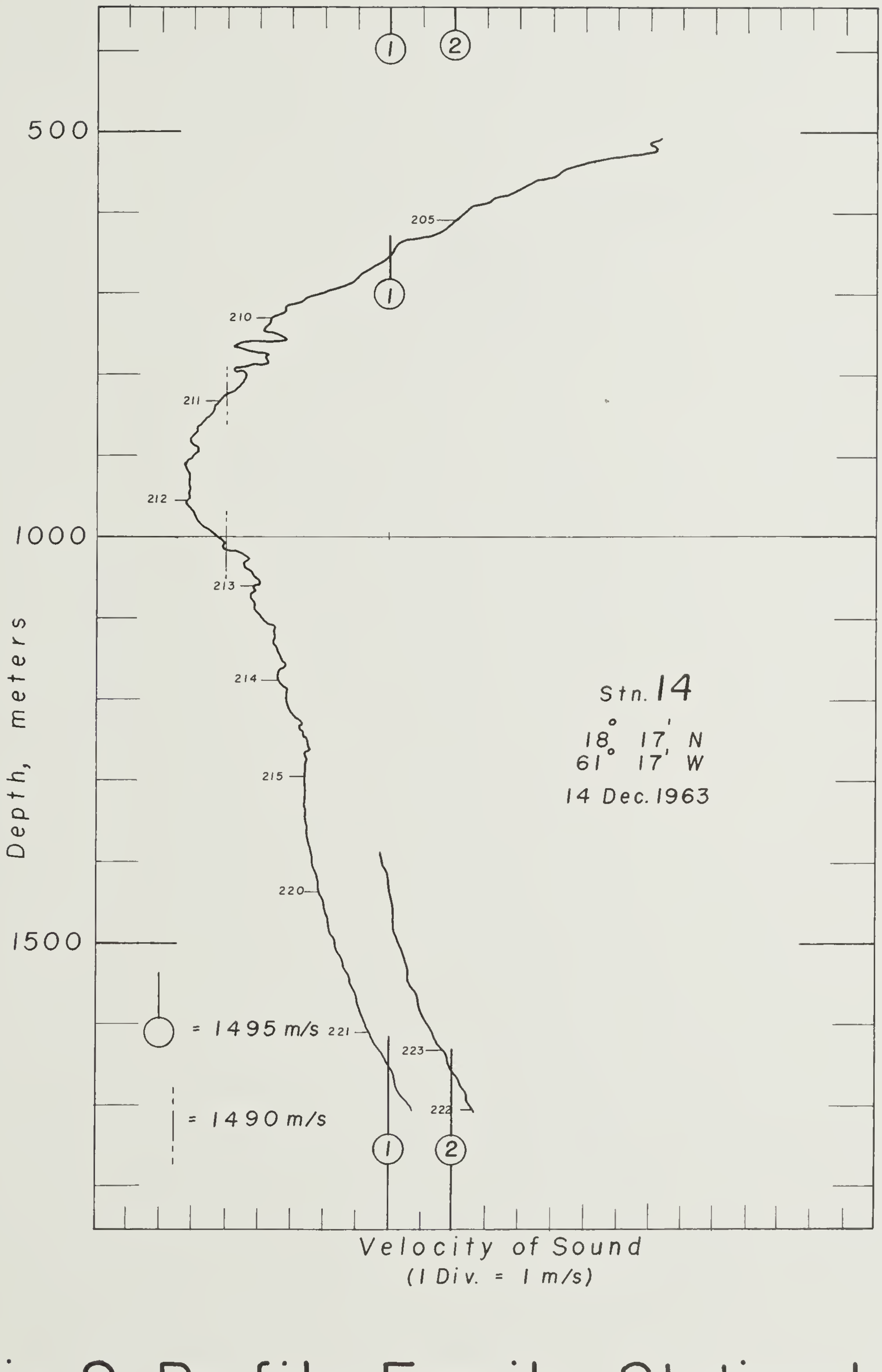

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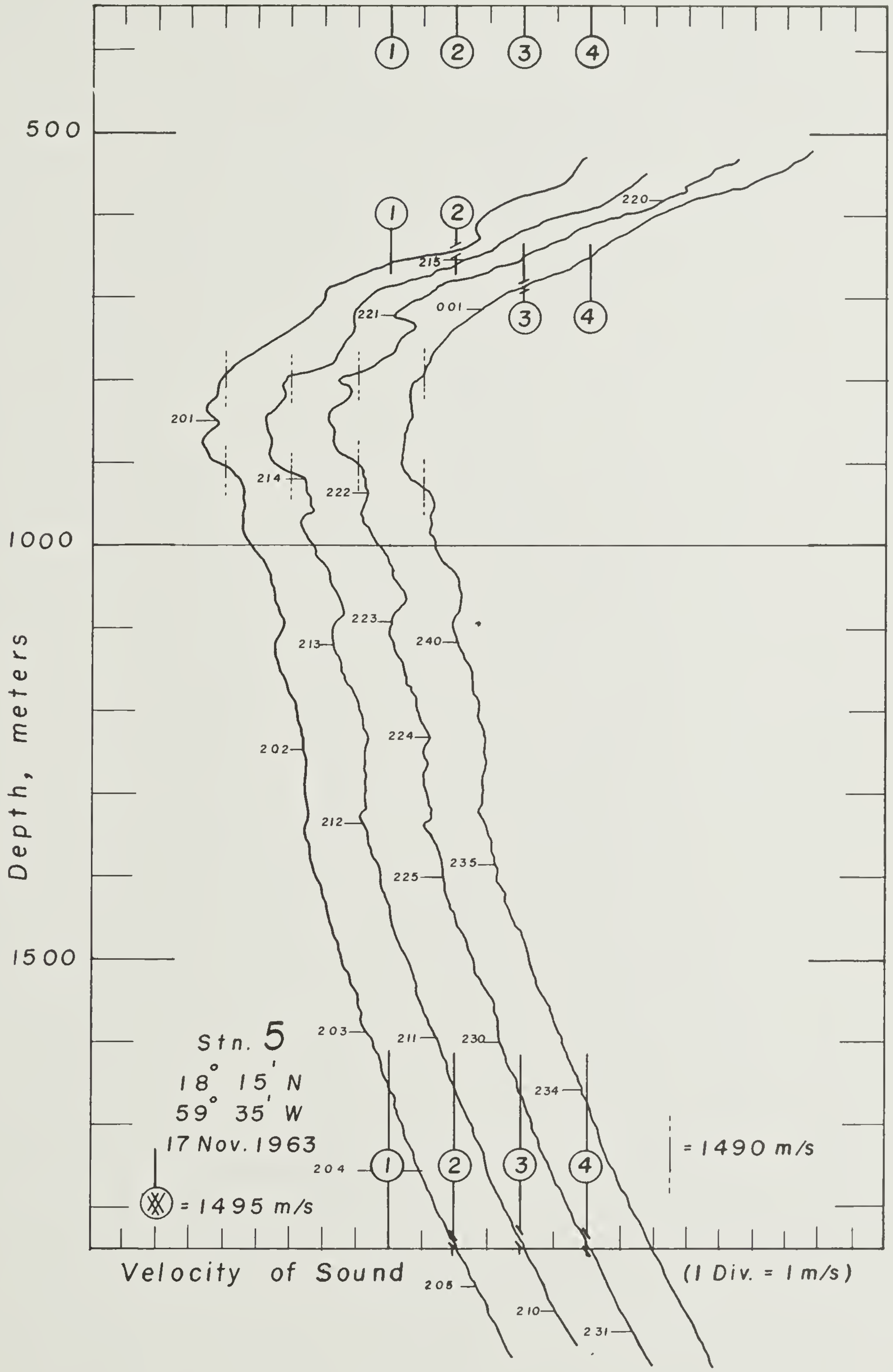

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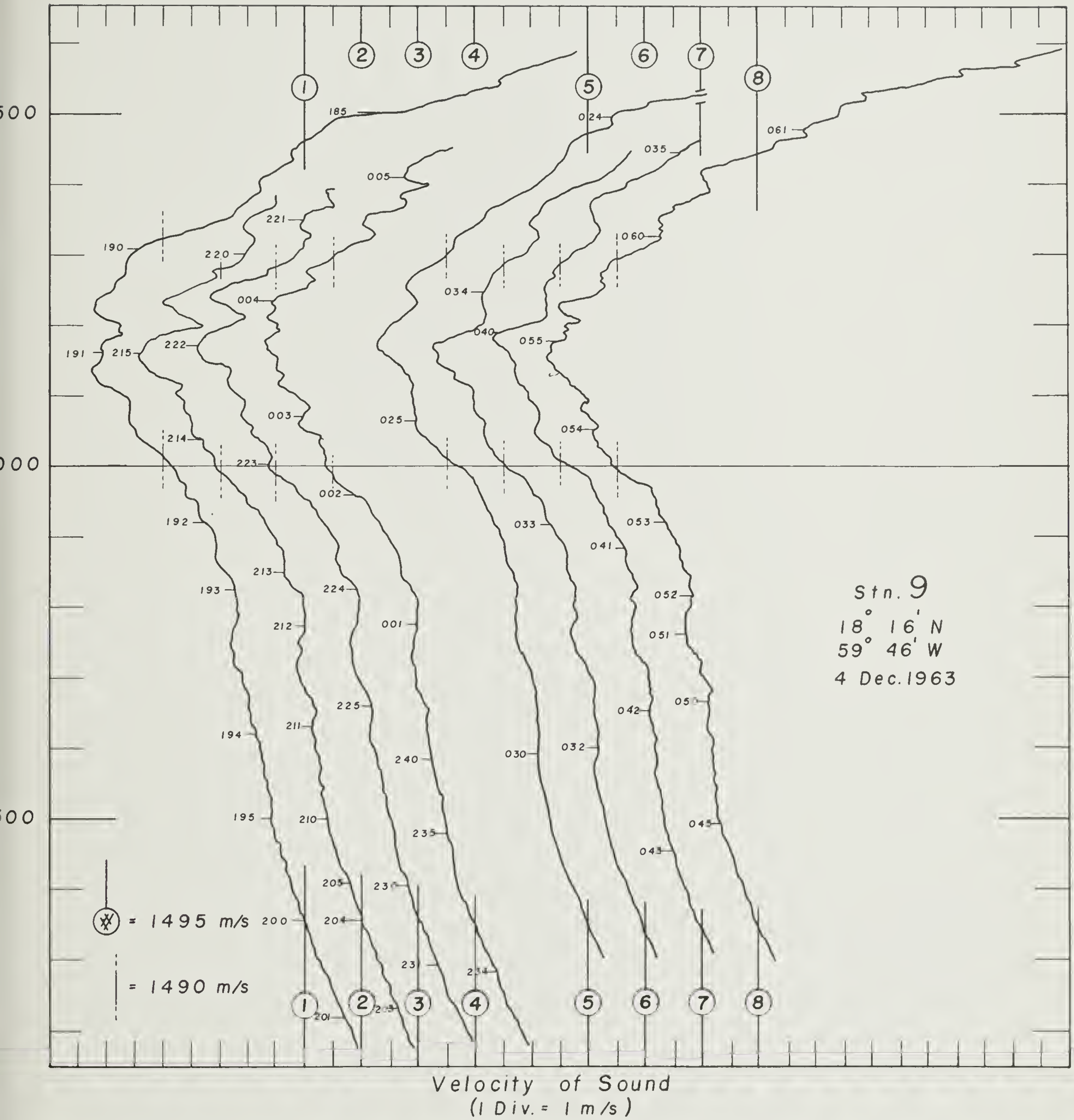

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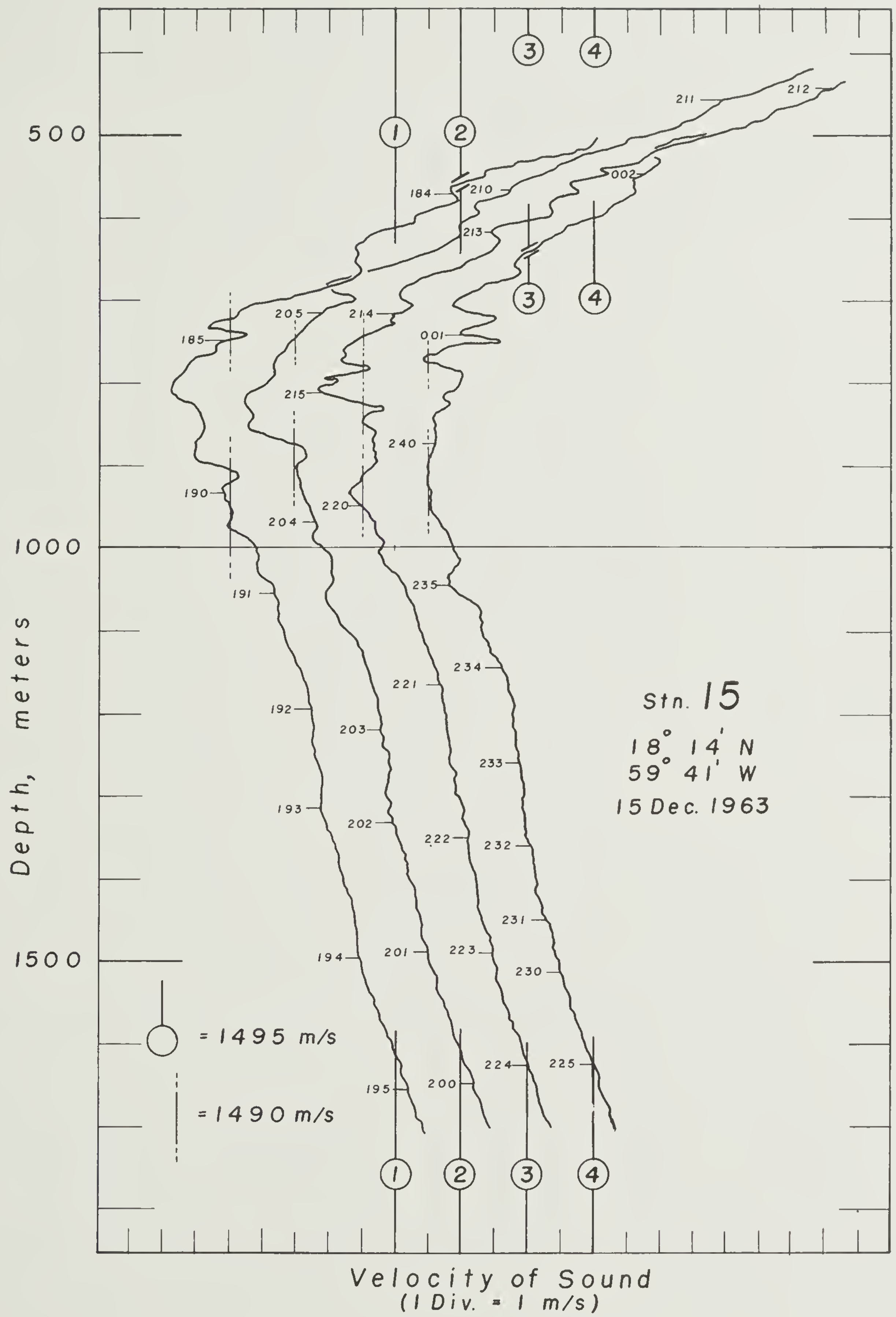

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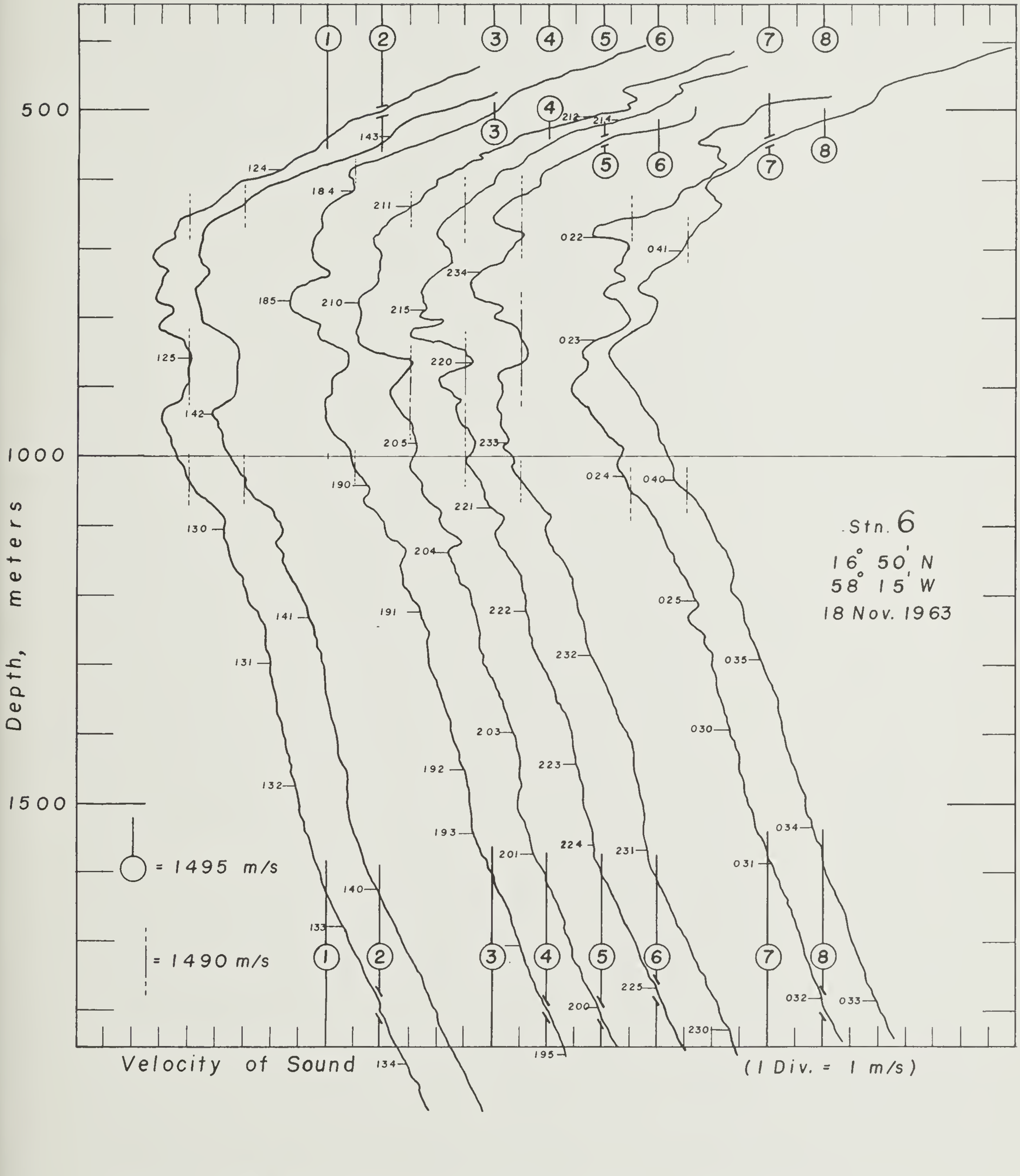

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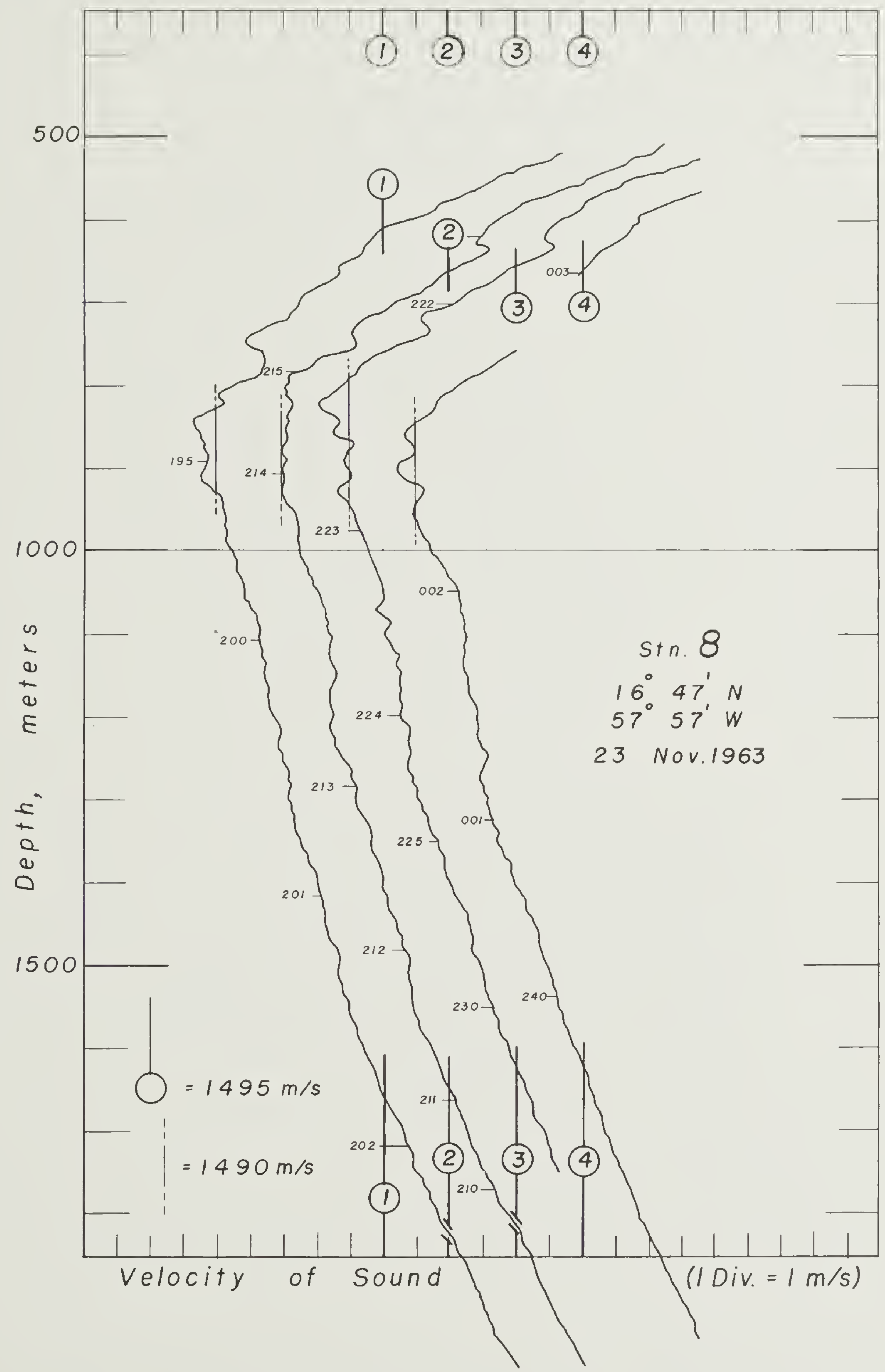

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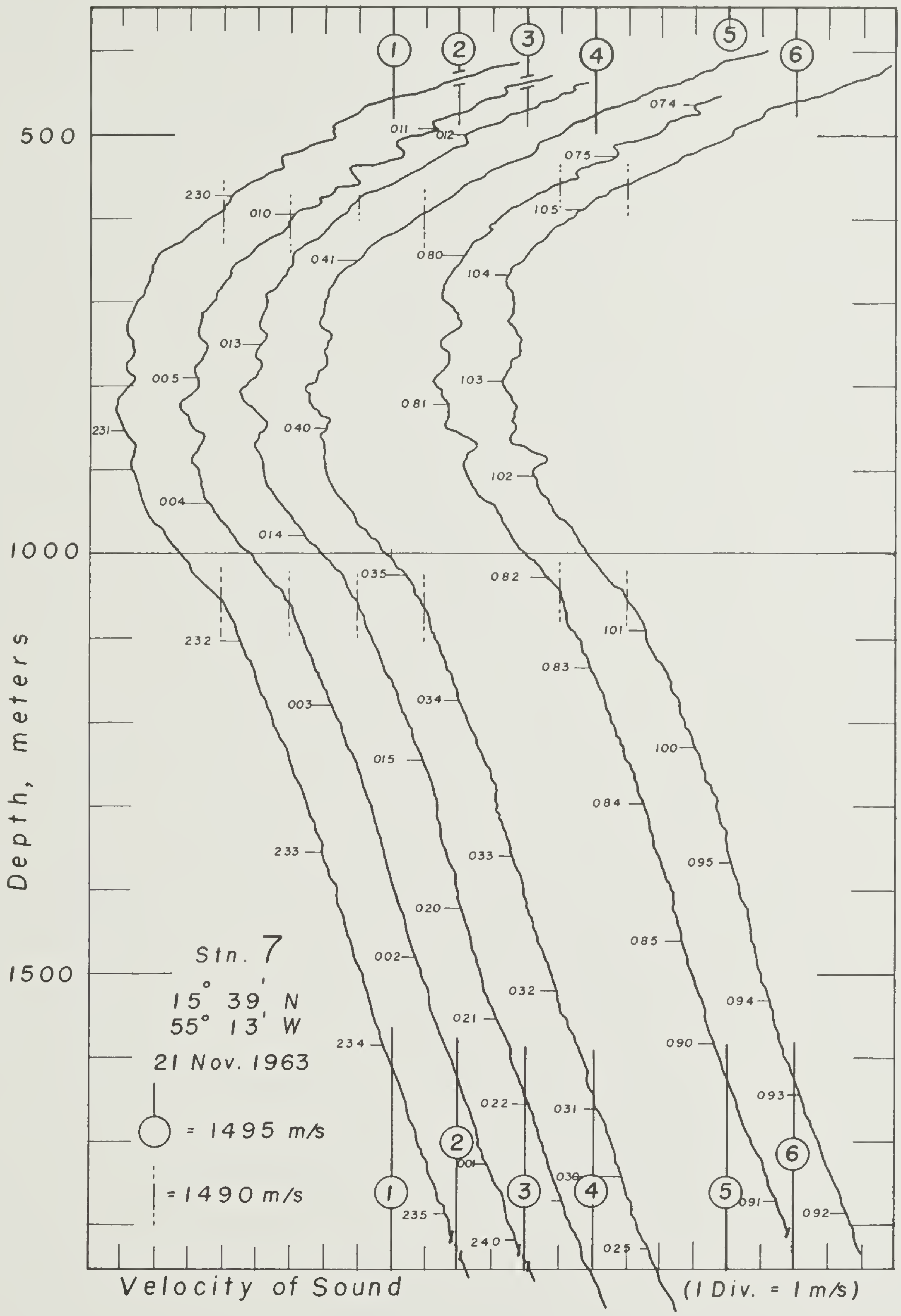

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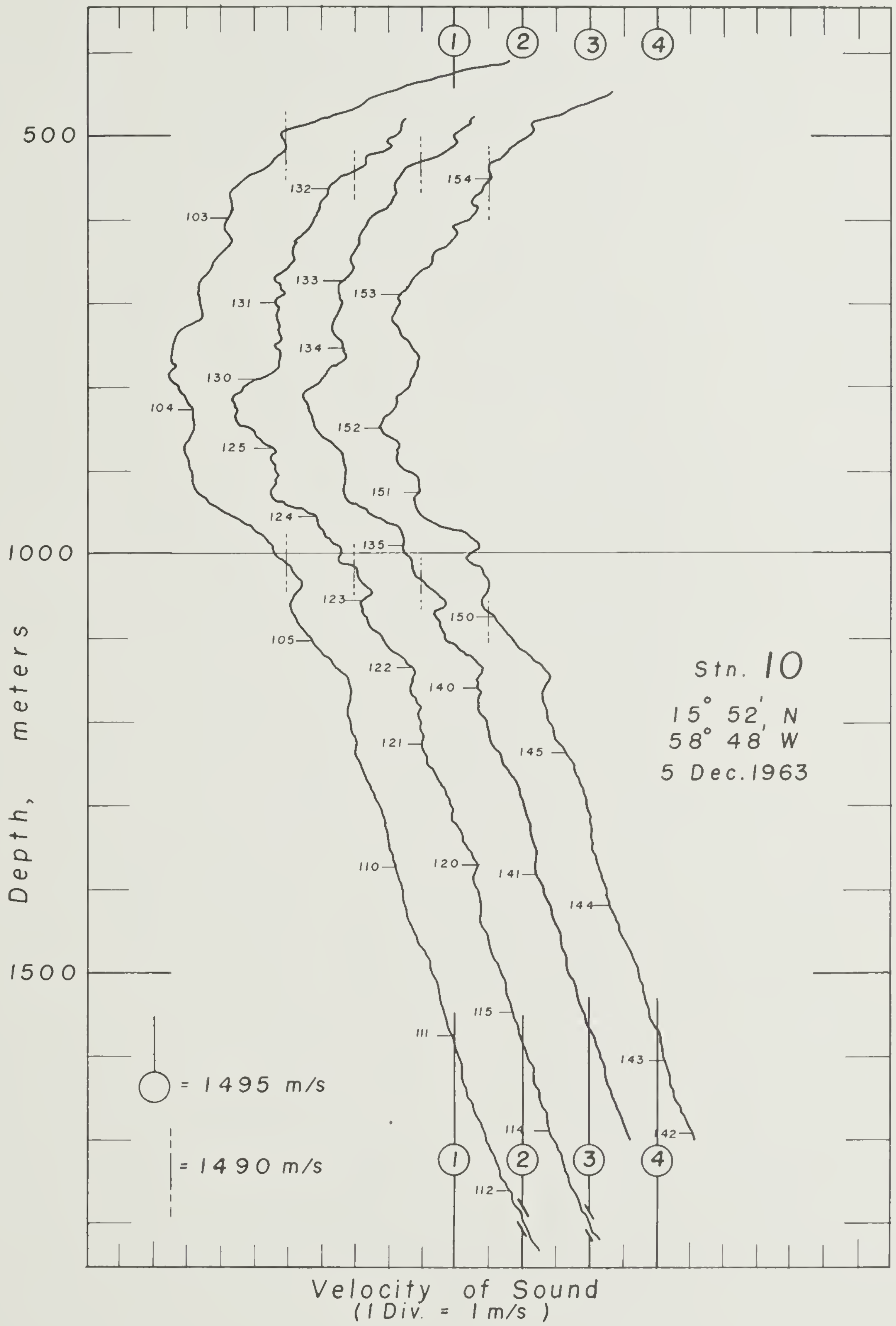

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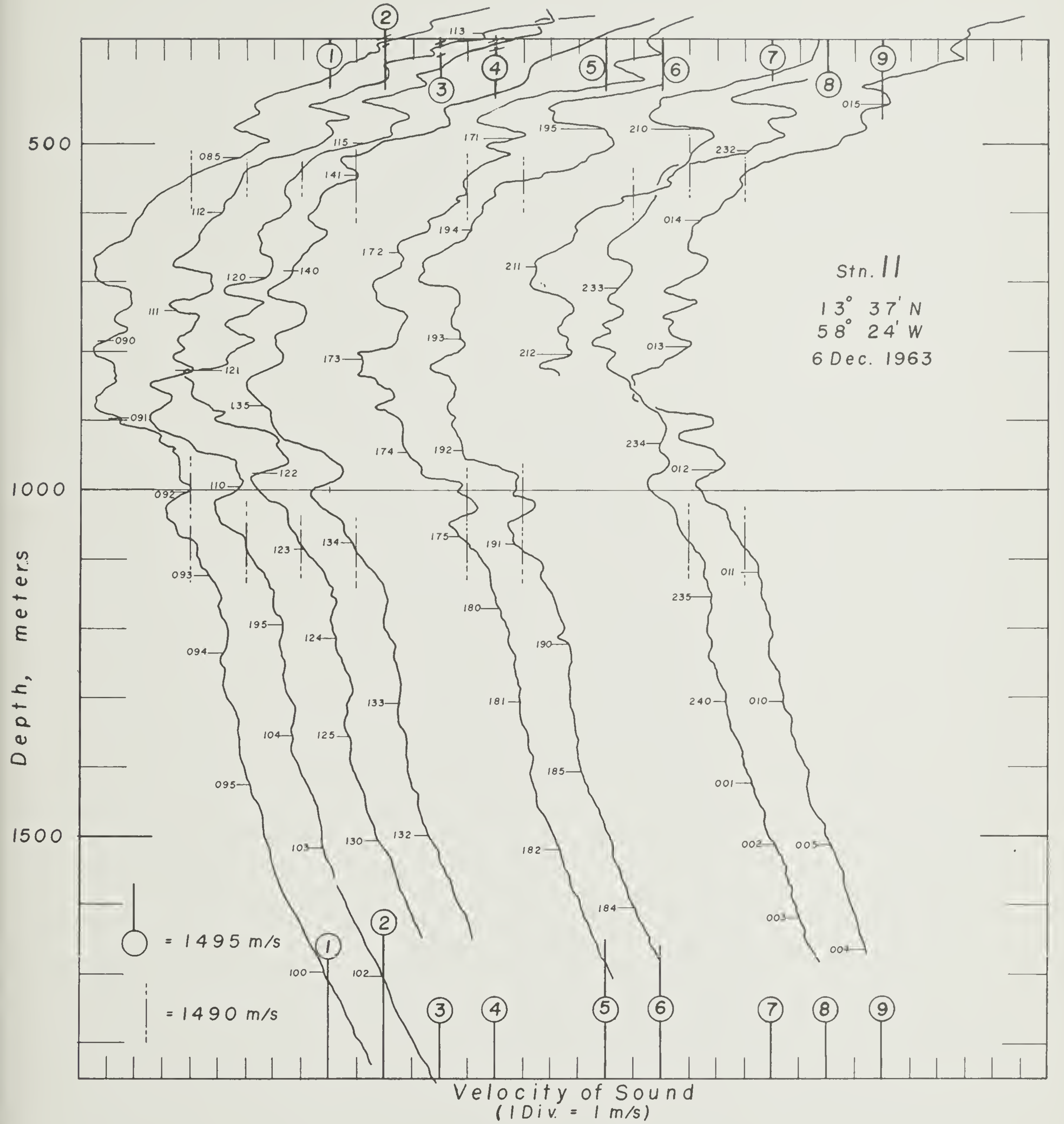

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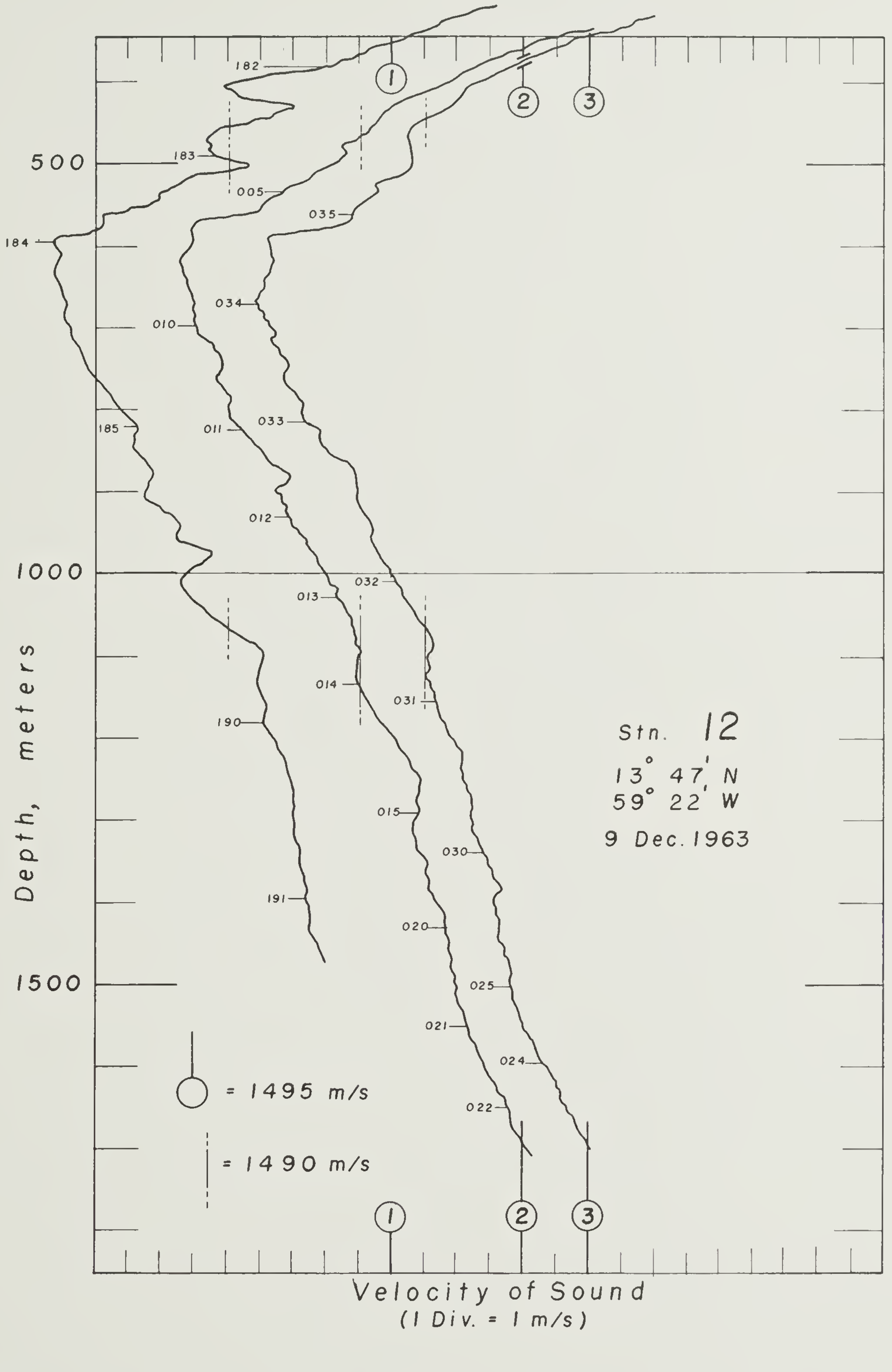

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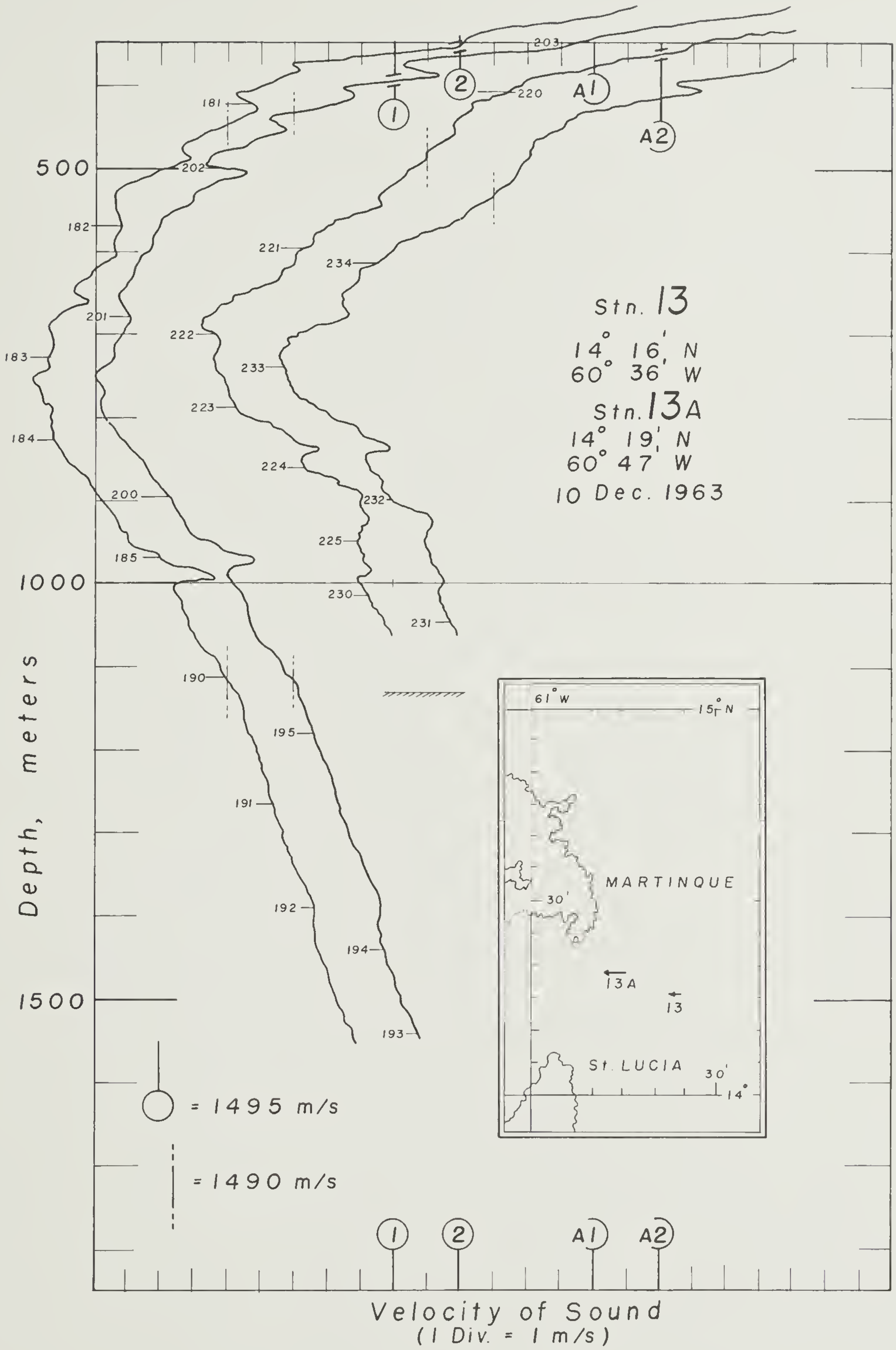

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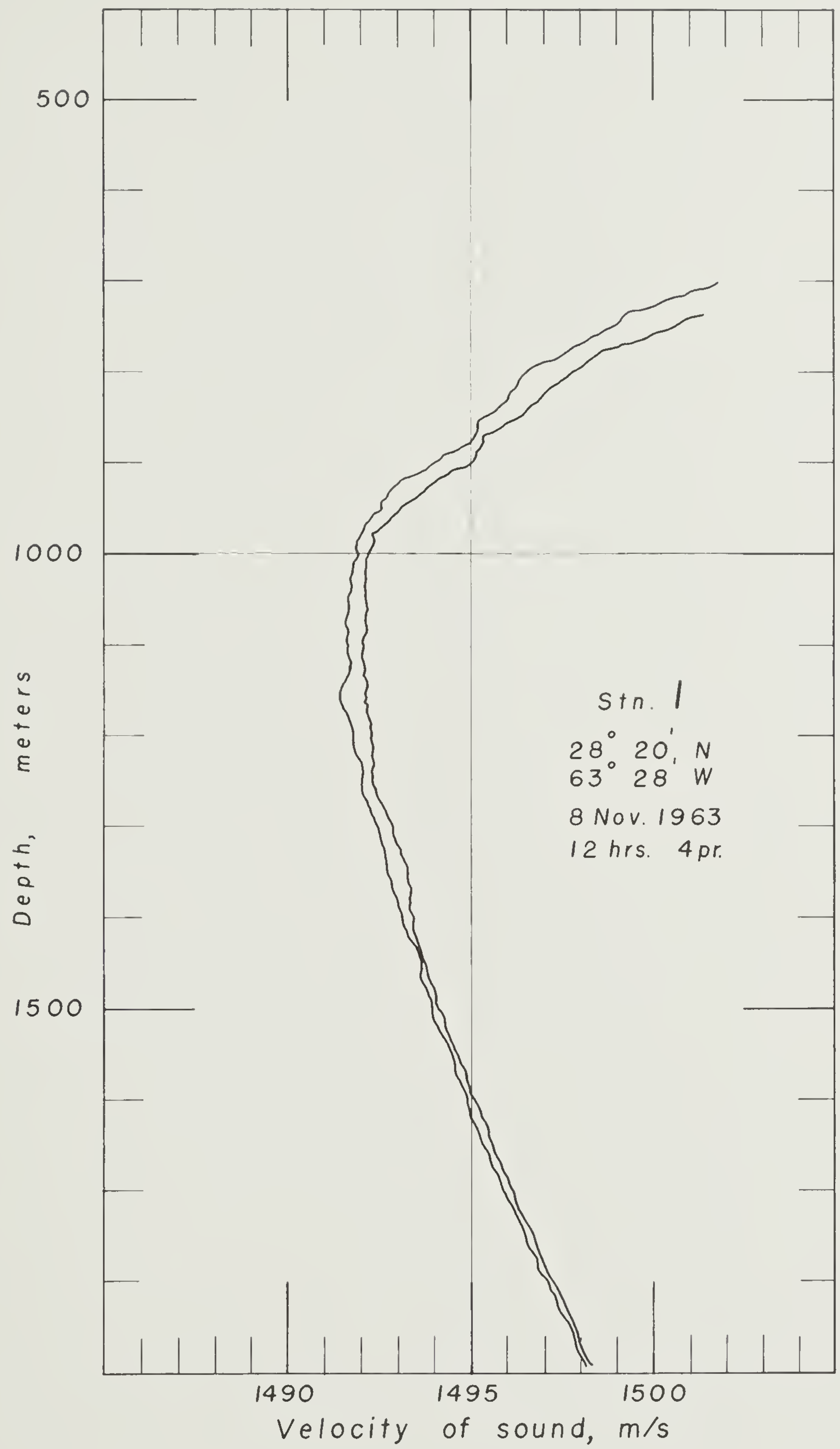
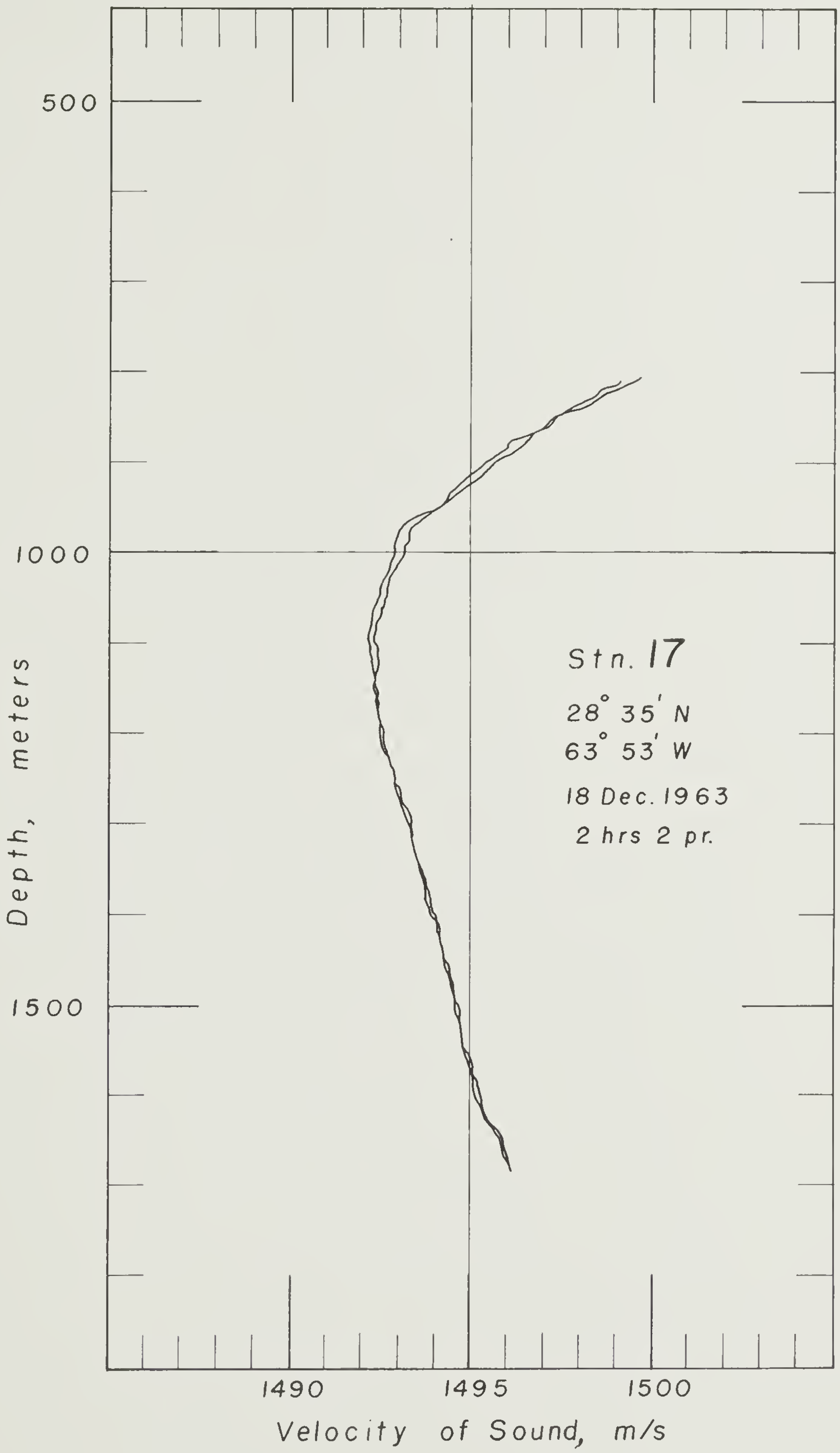


Fig. 20. Envelope of Profiles, Station I.



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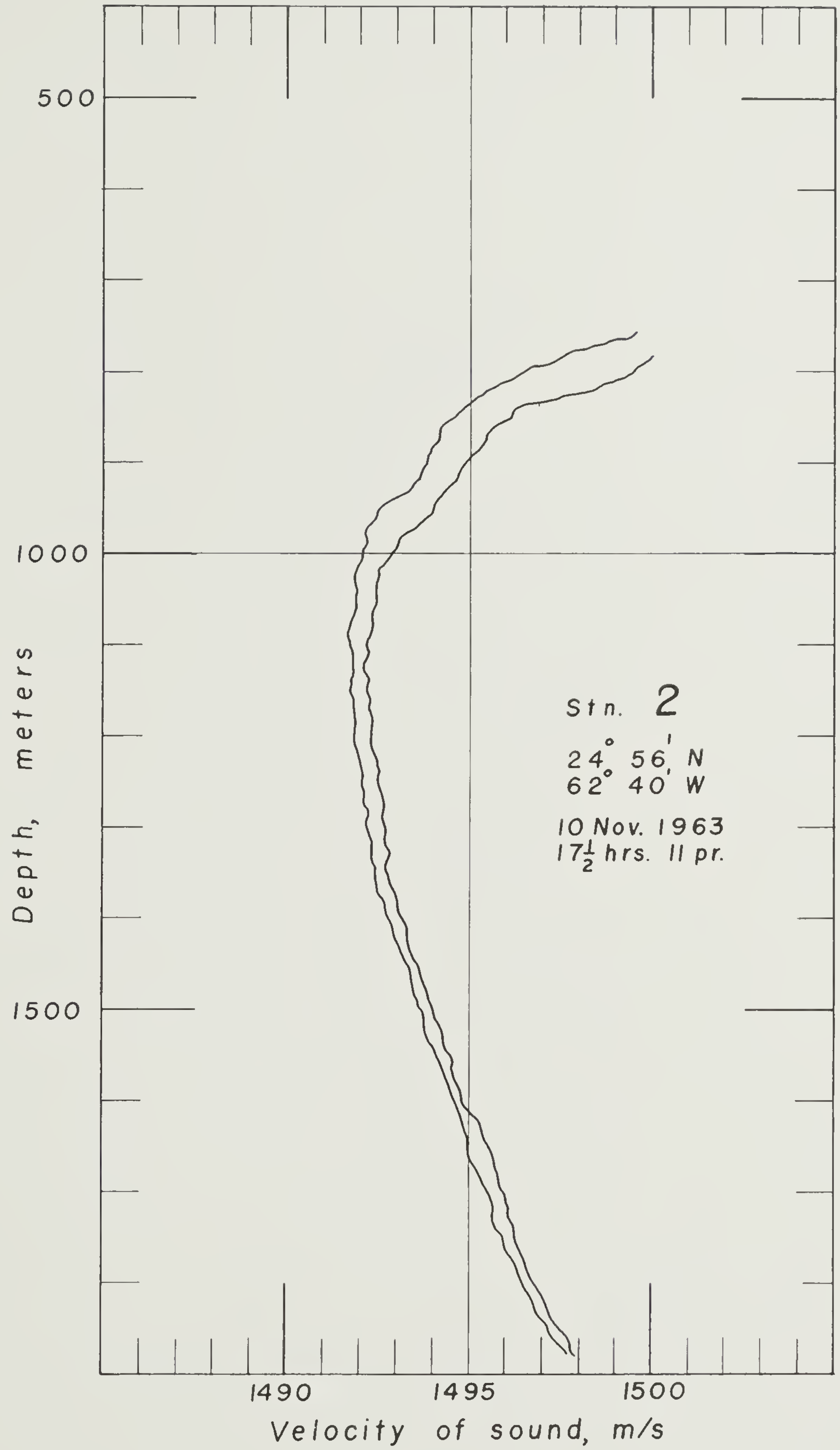

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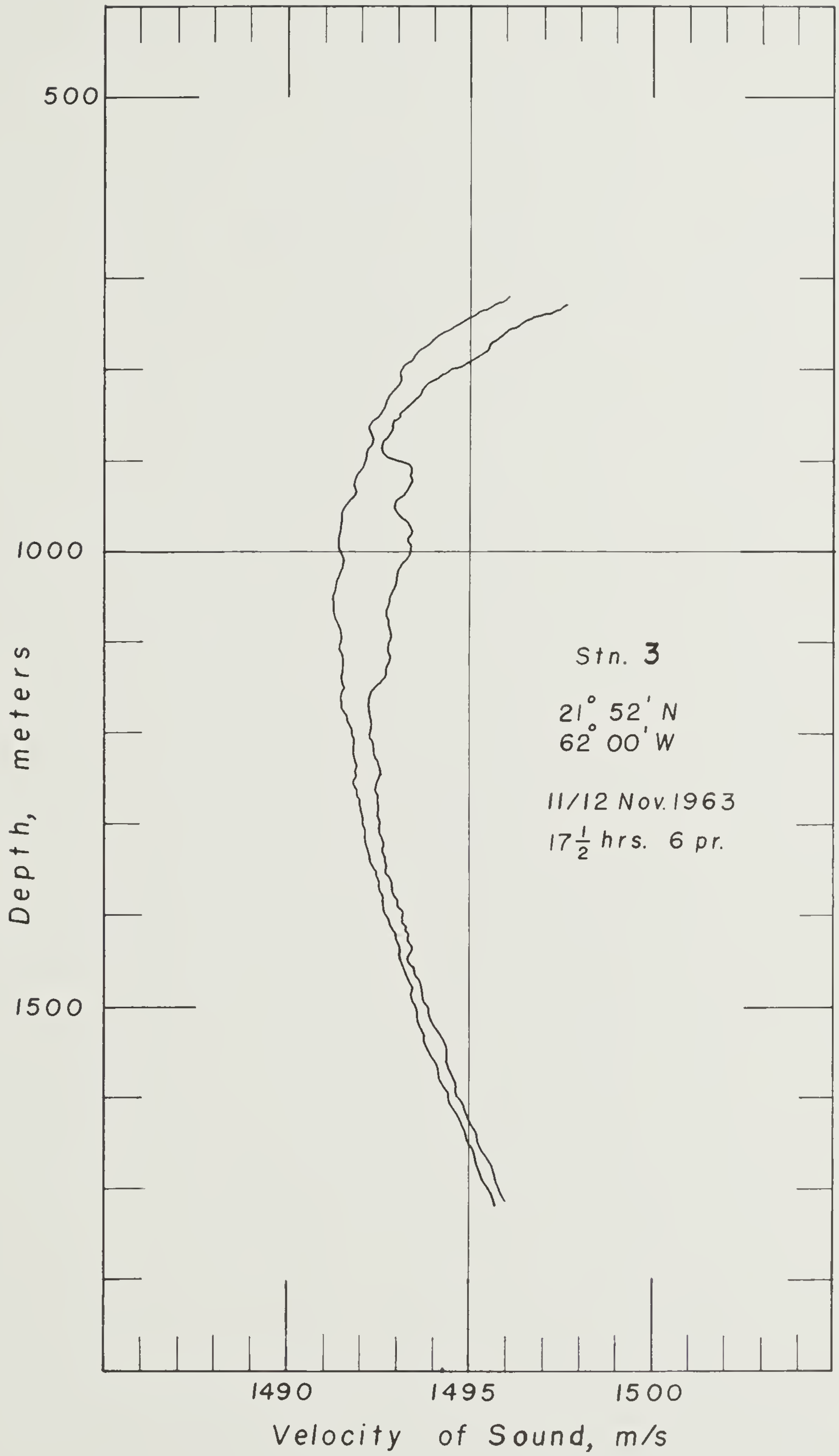

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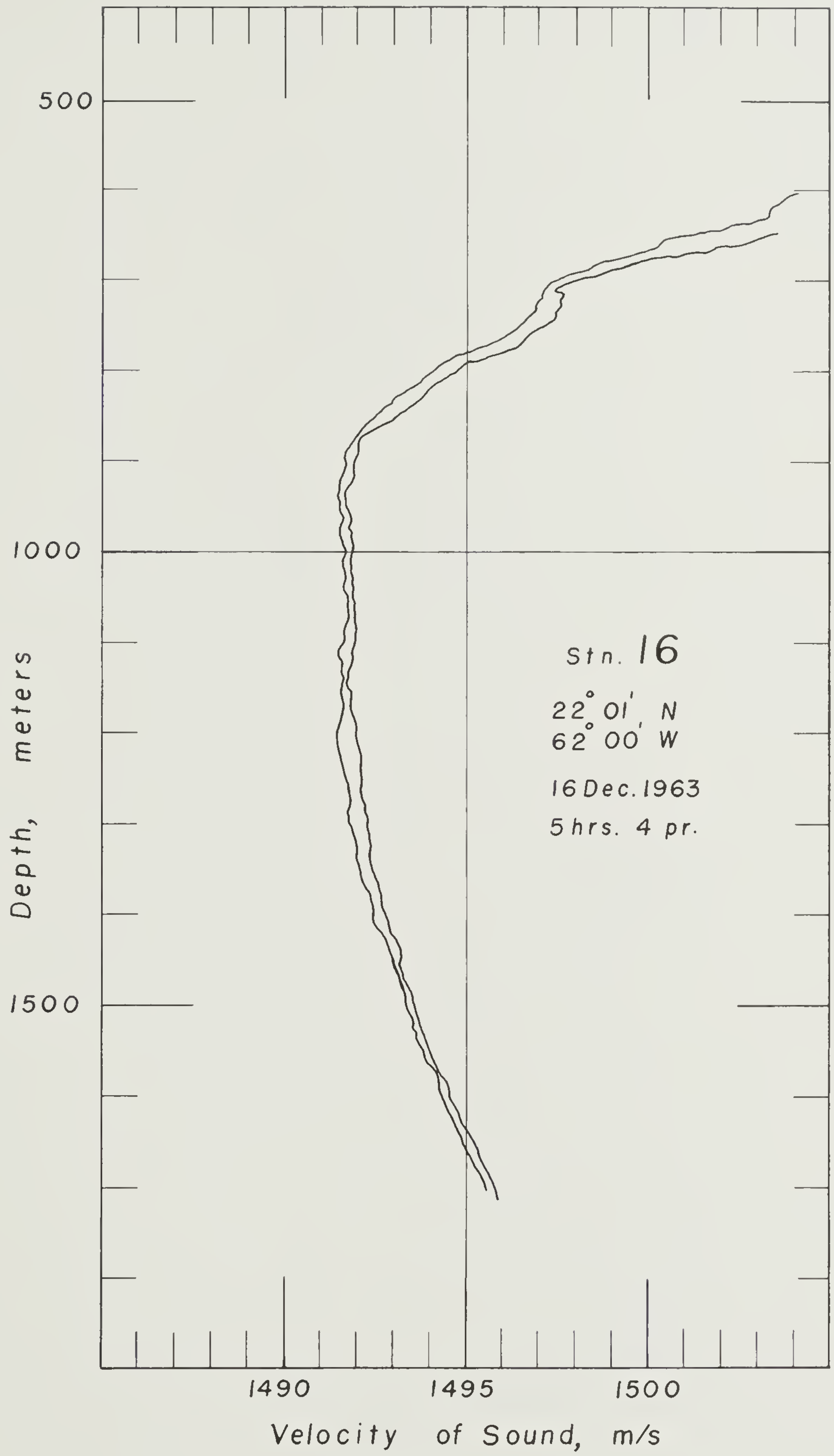

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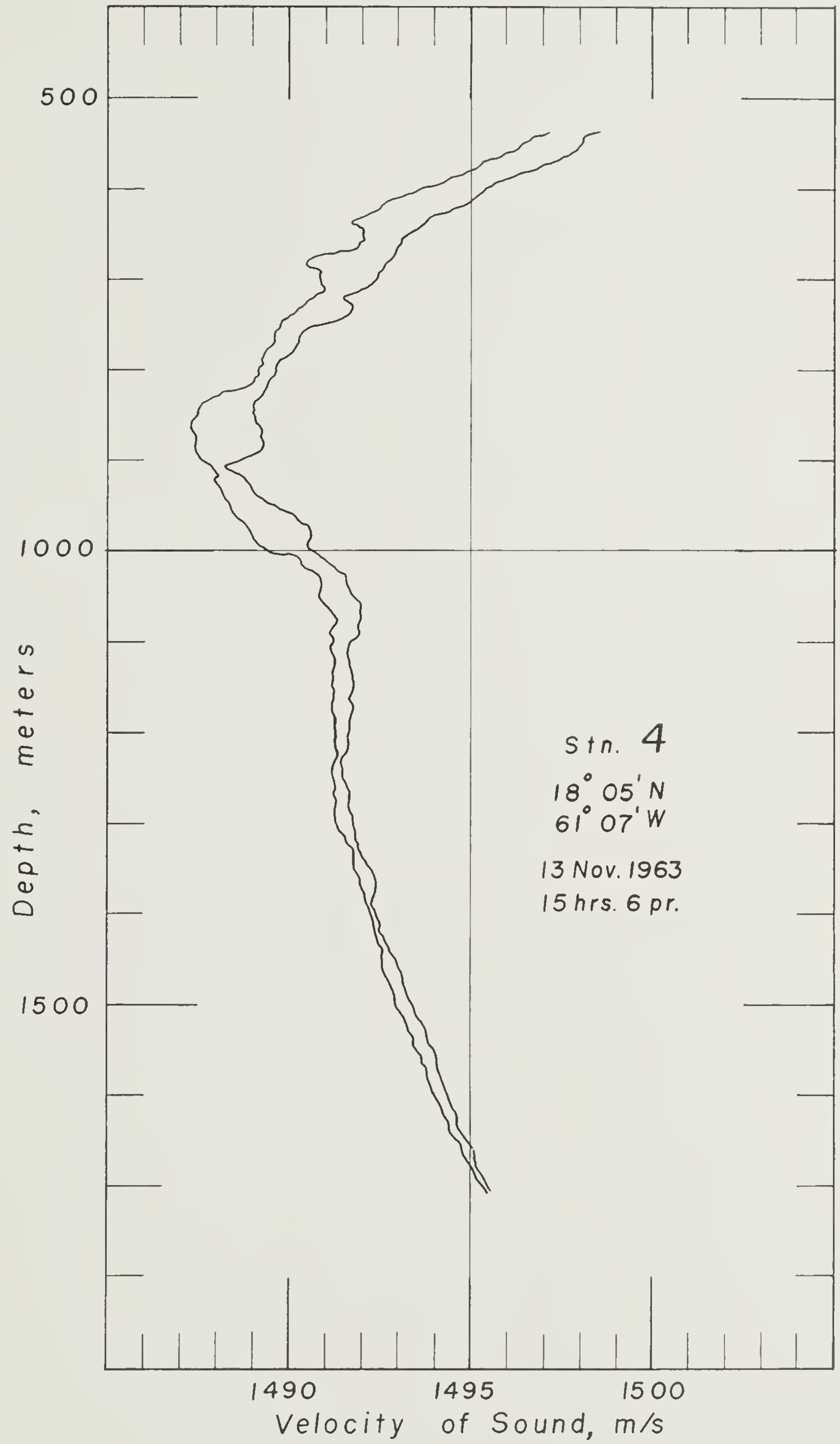

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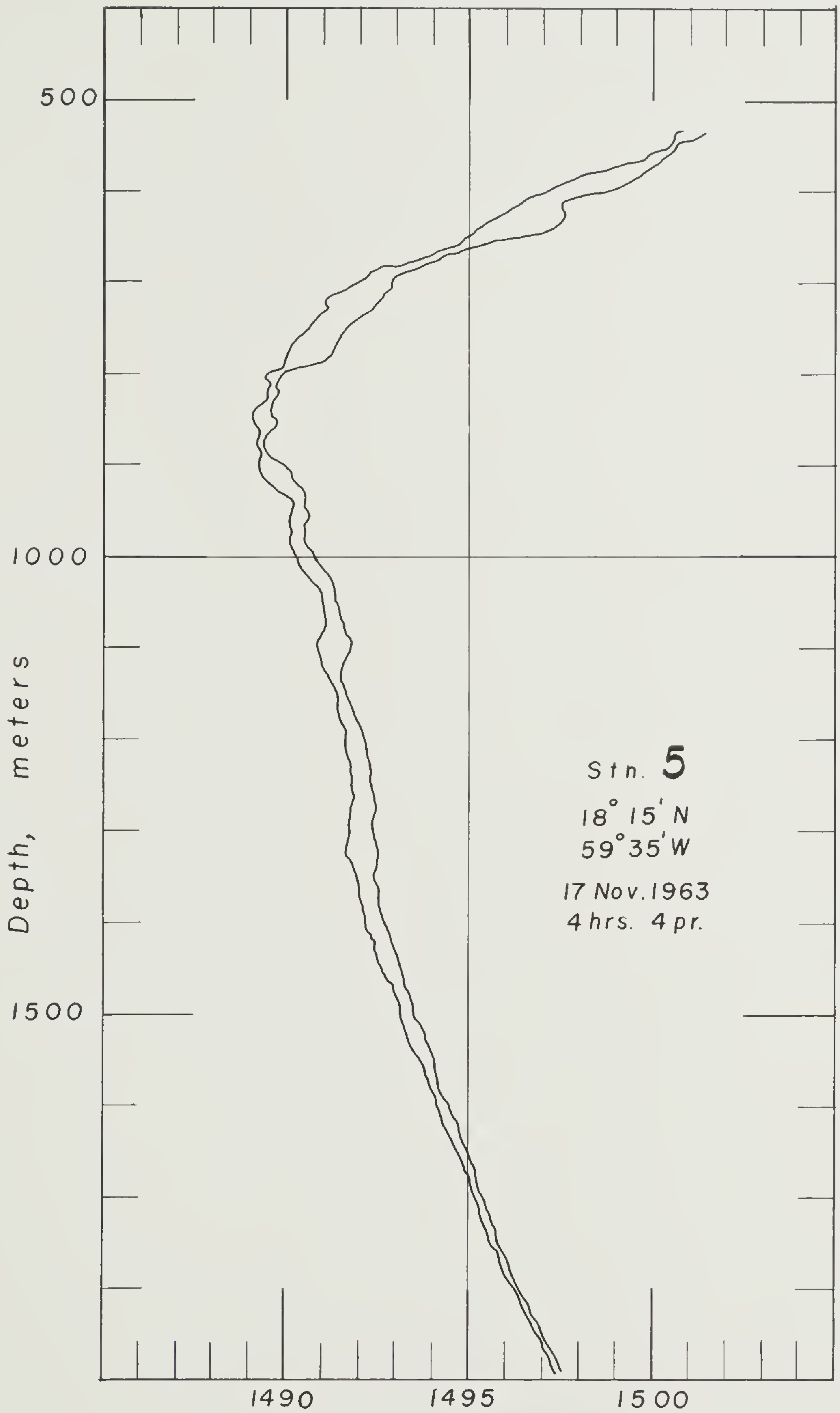

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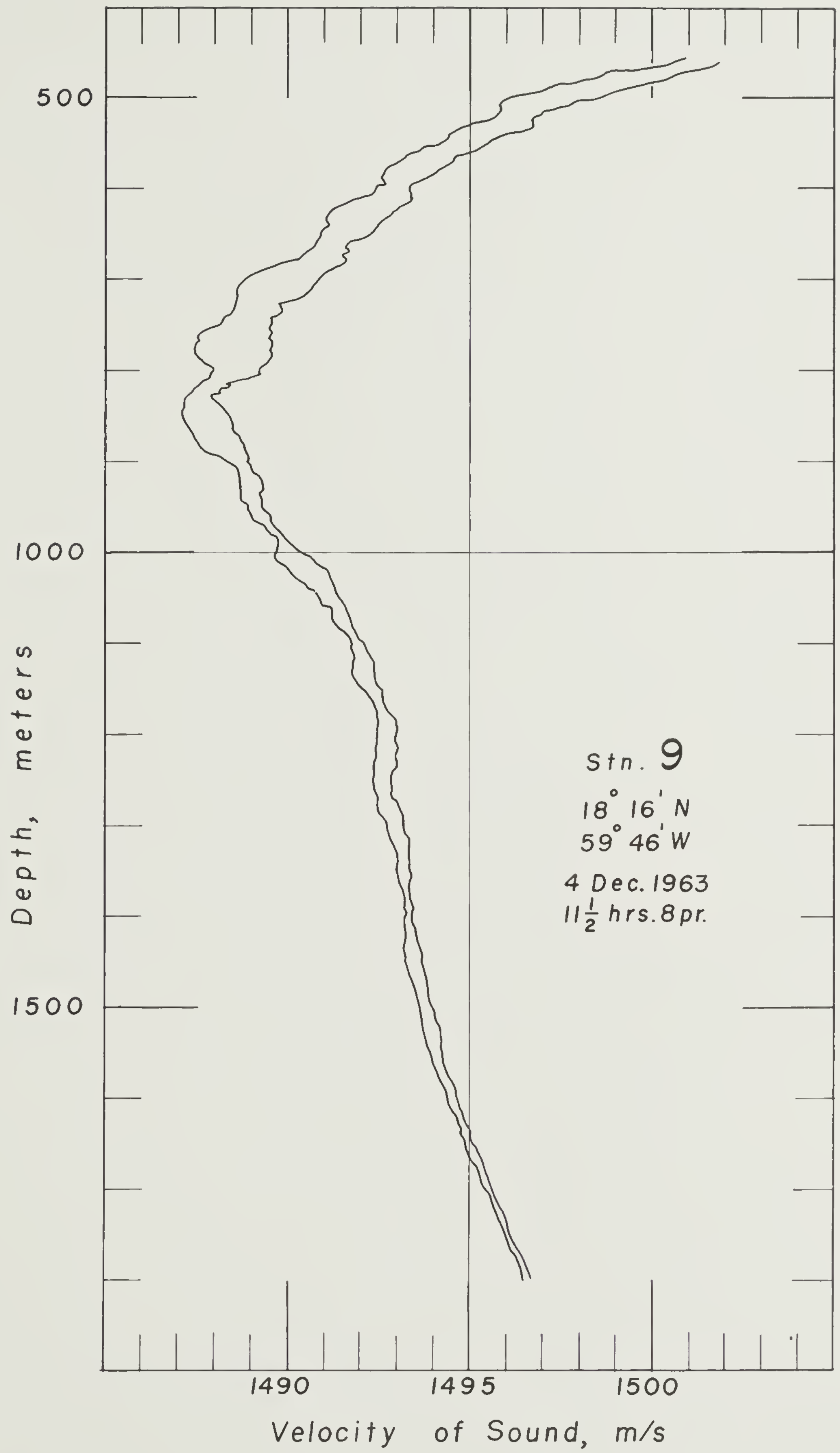

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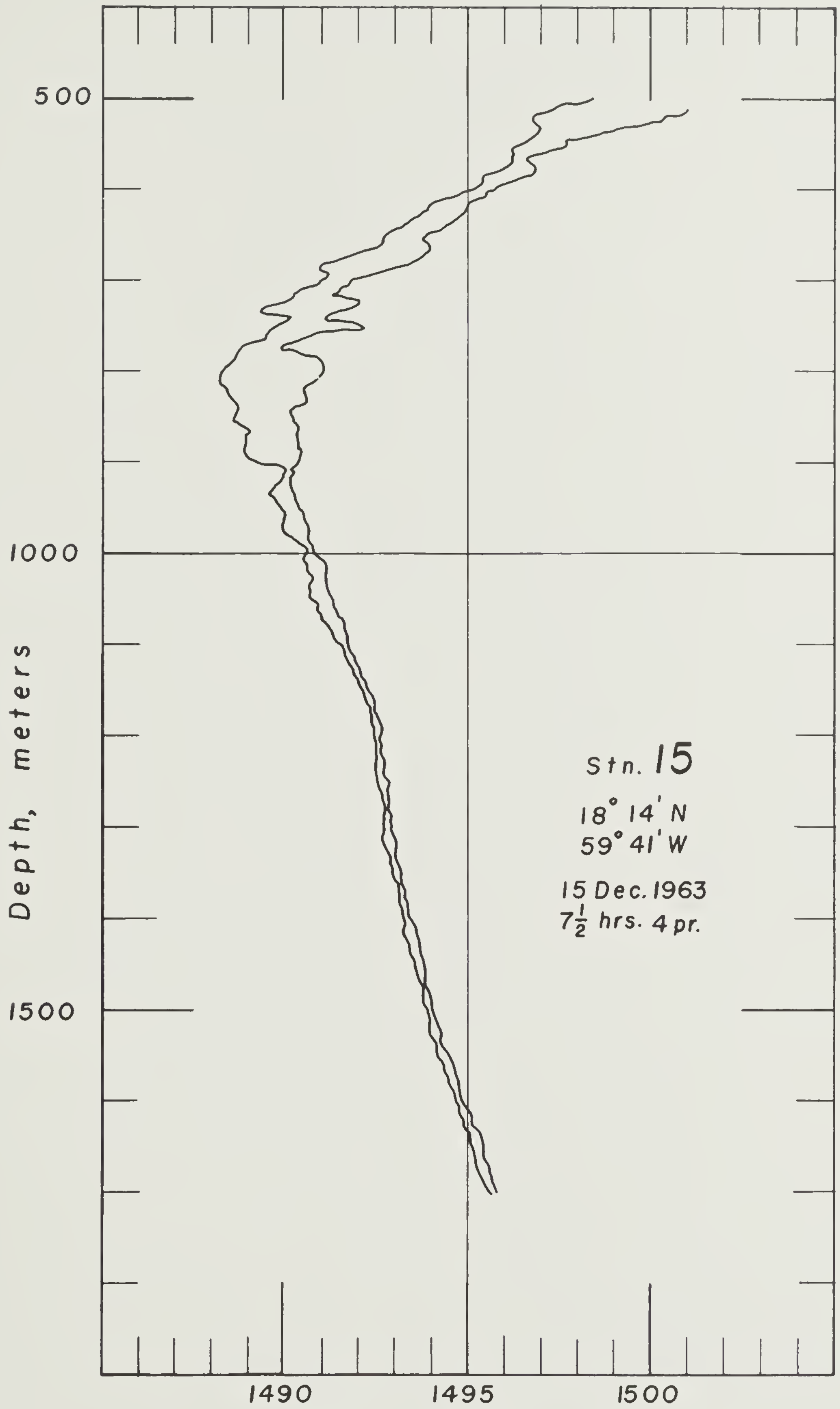

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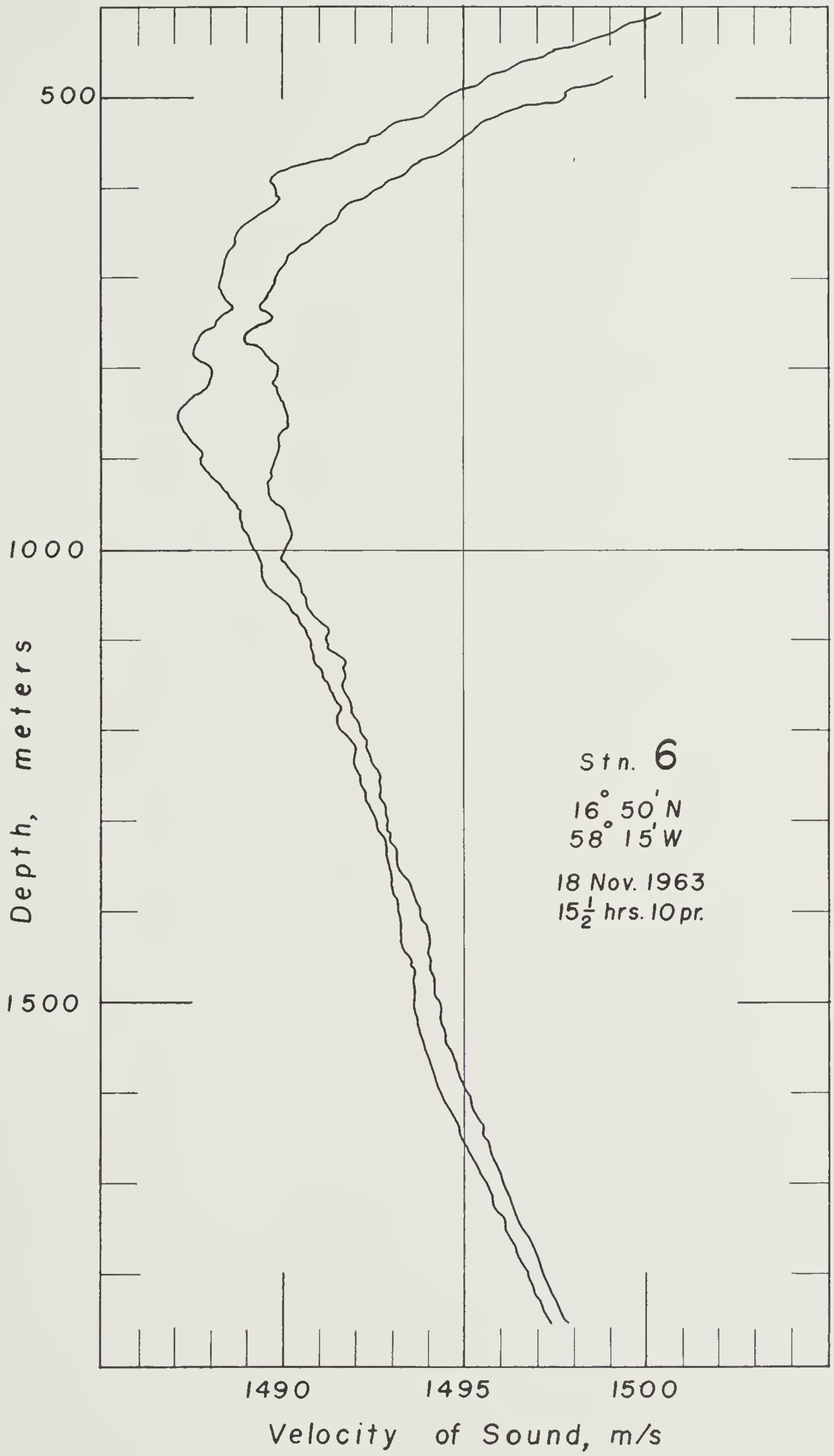

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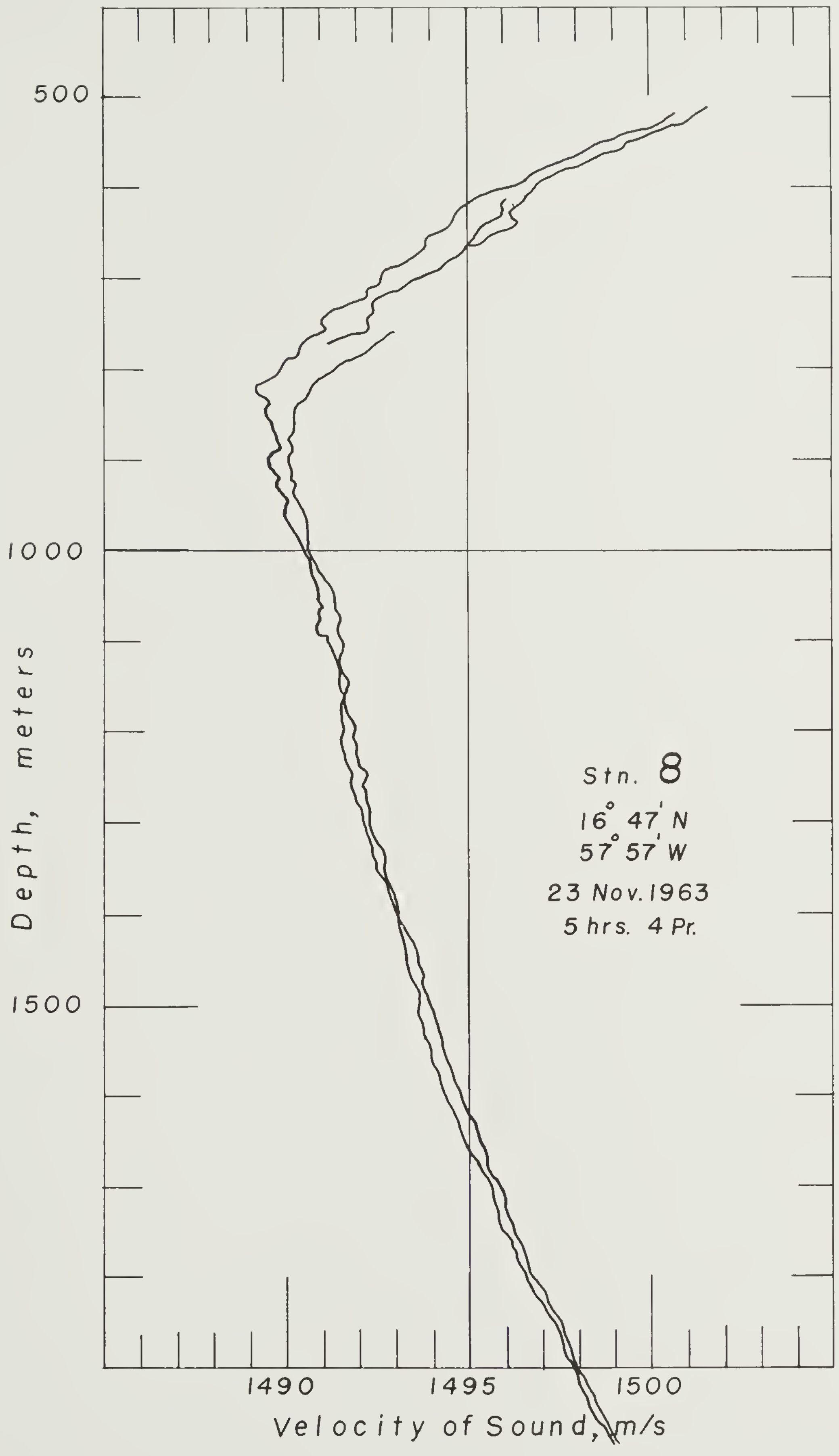

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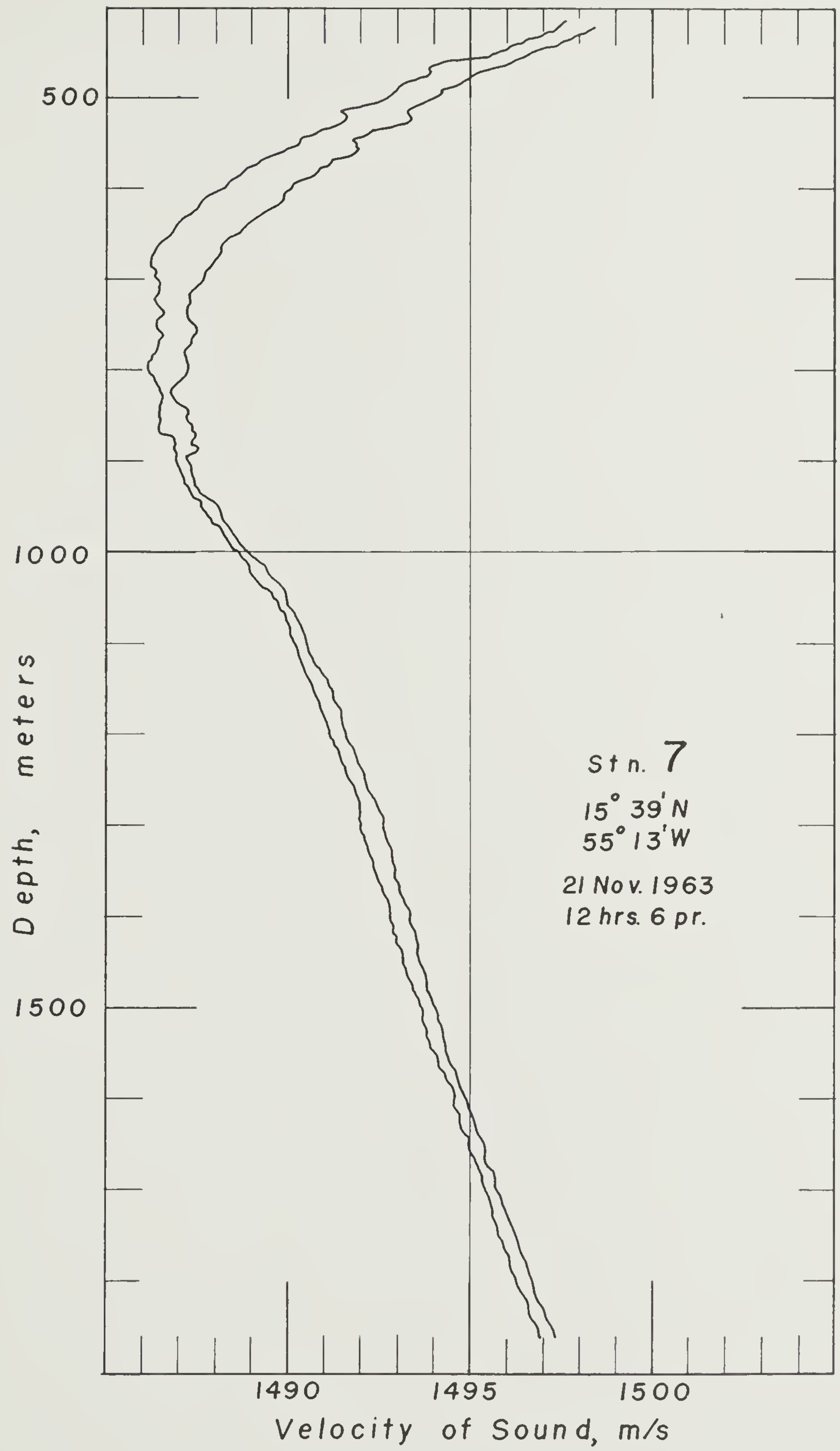

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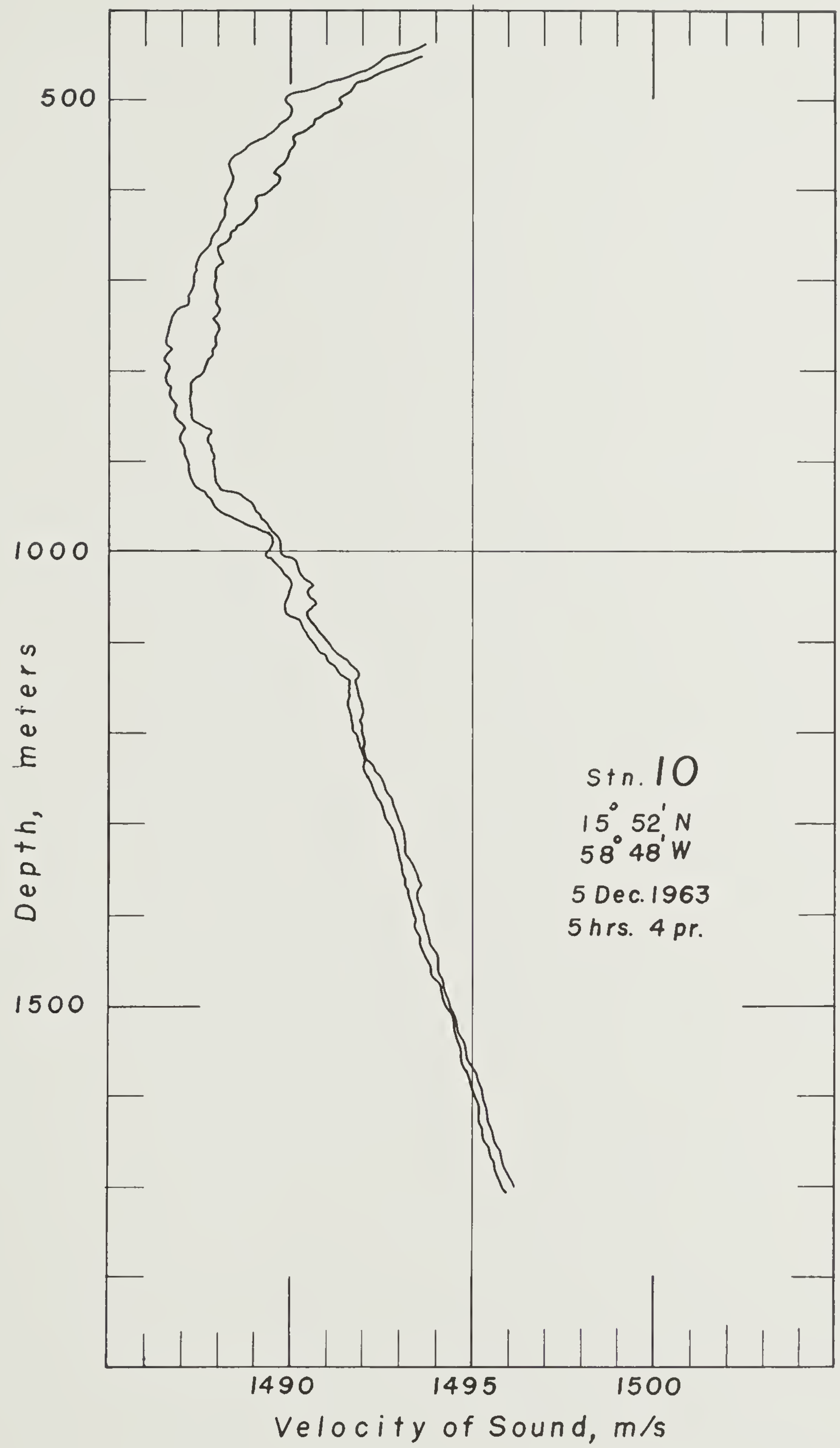

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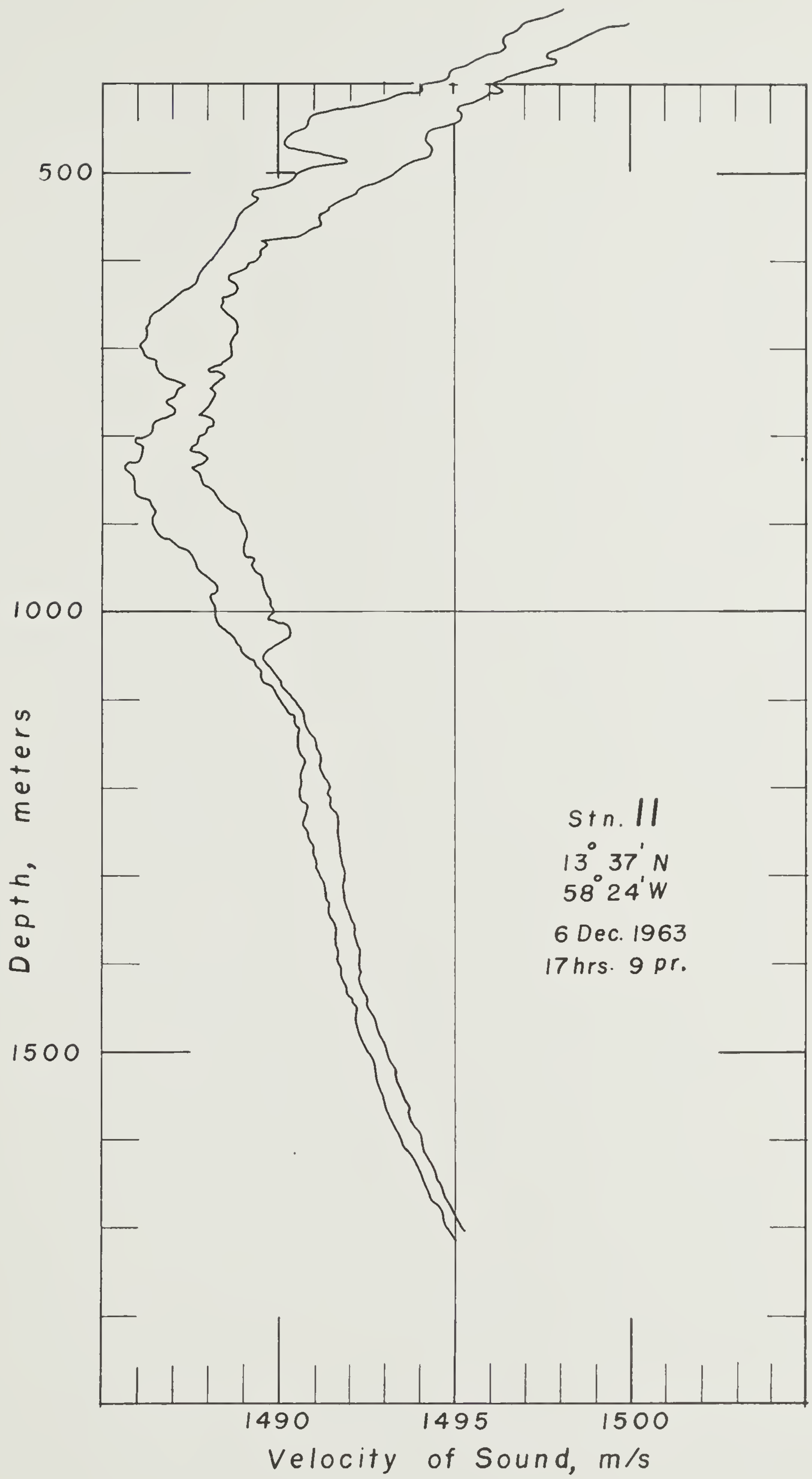

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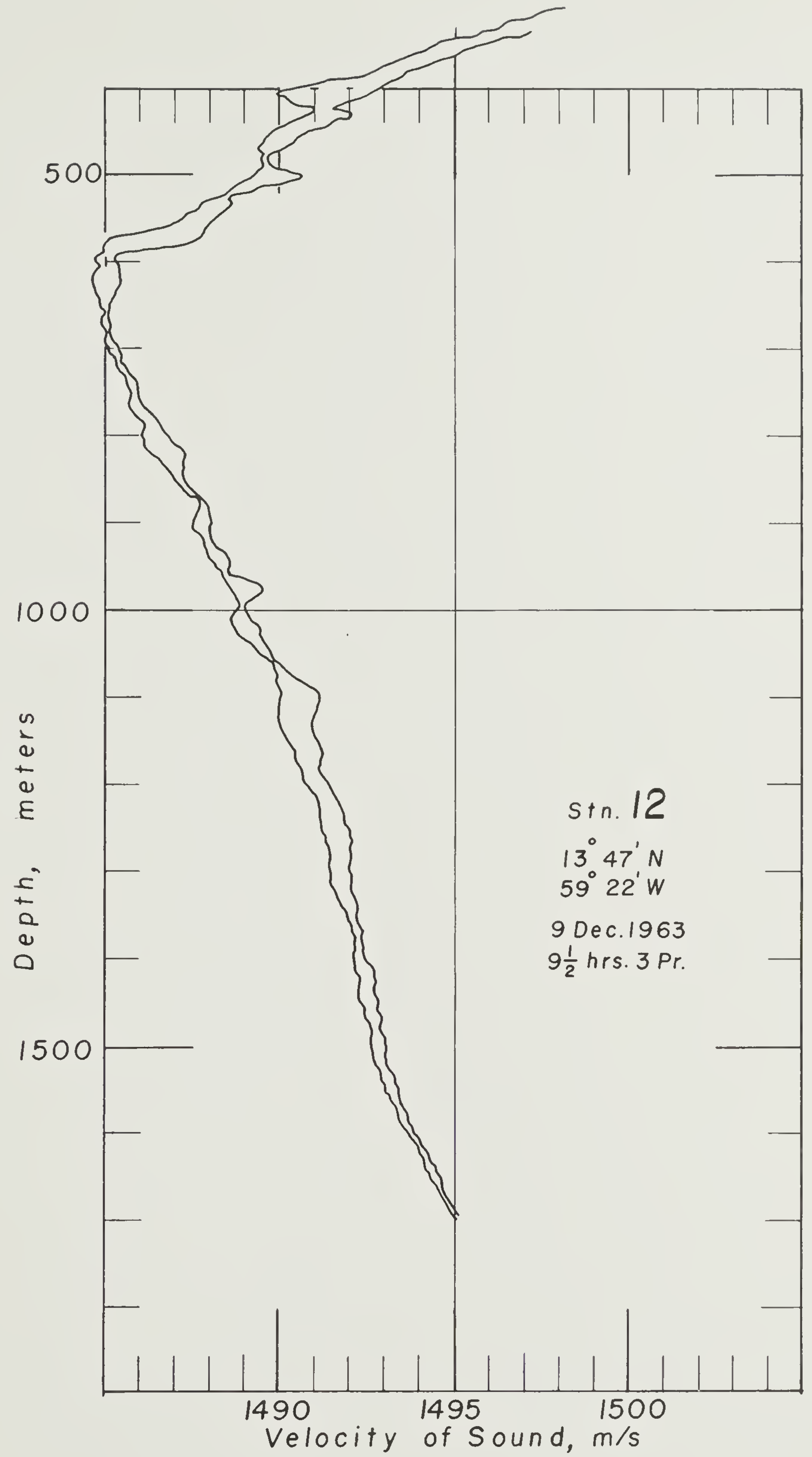

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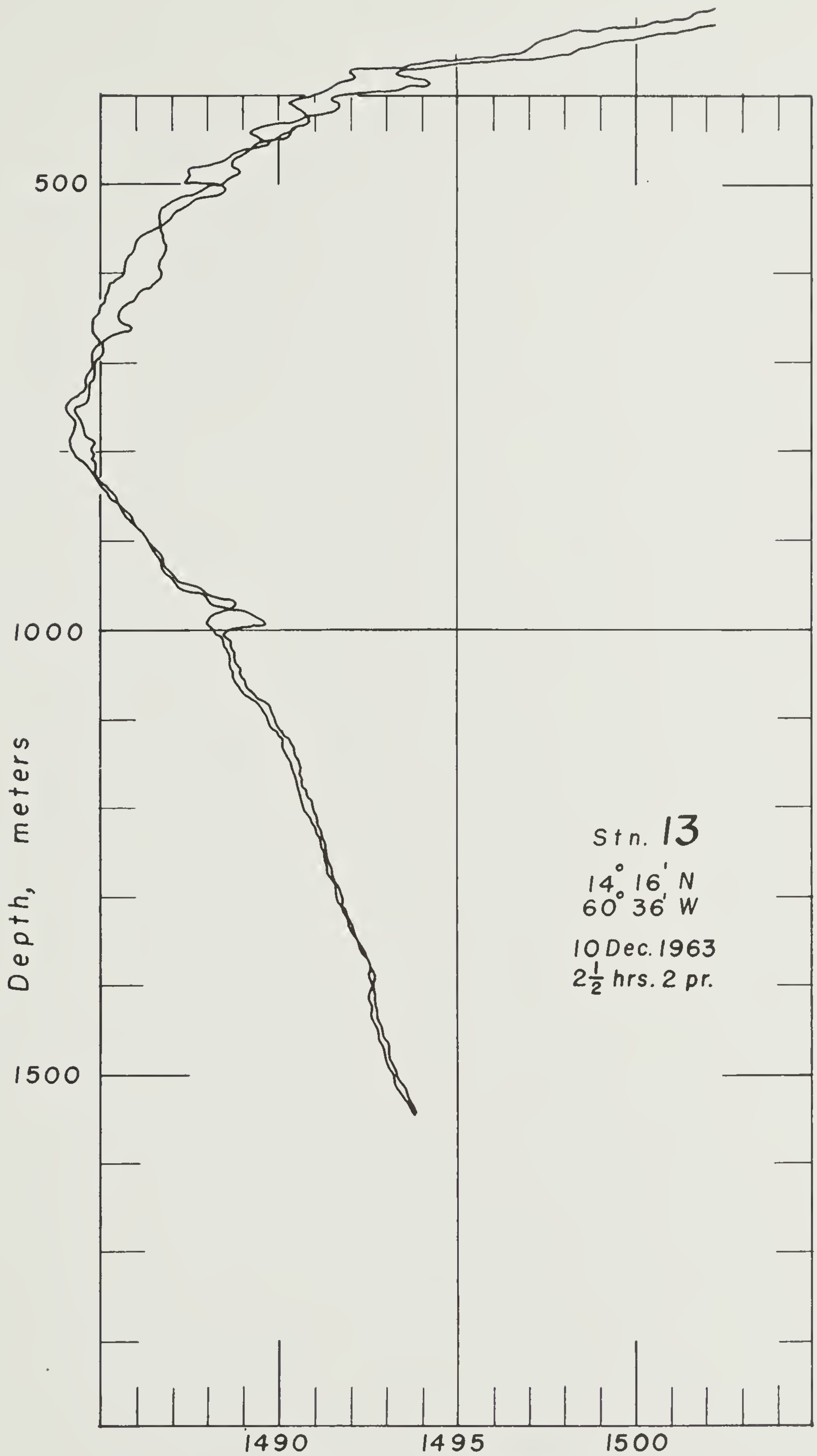

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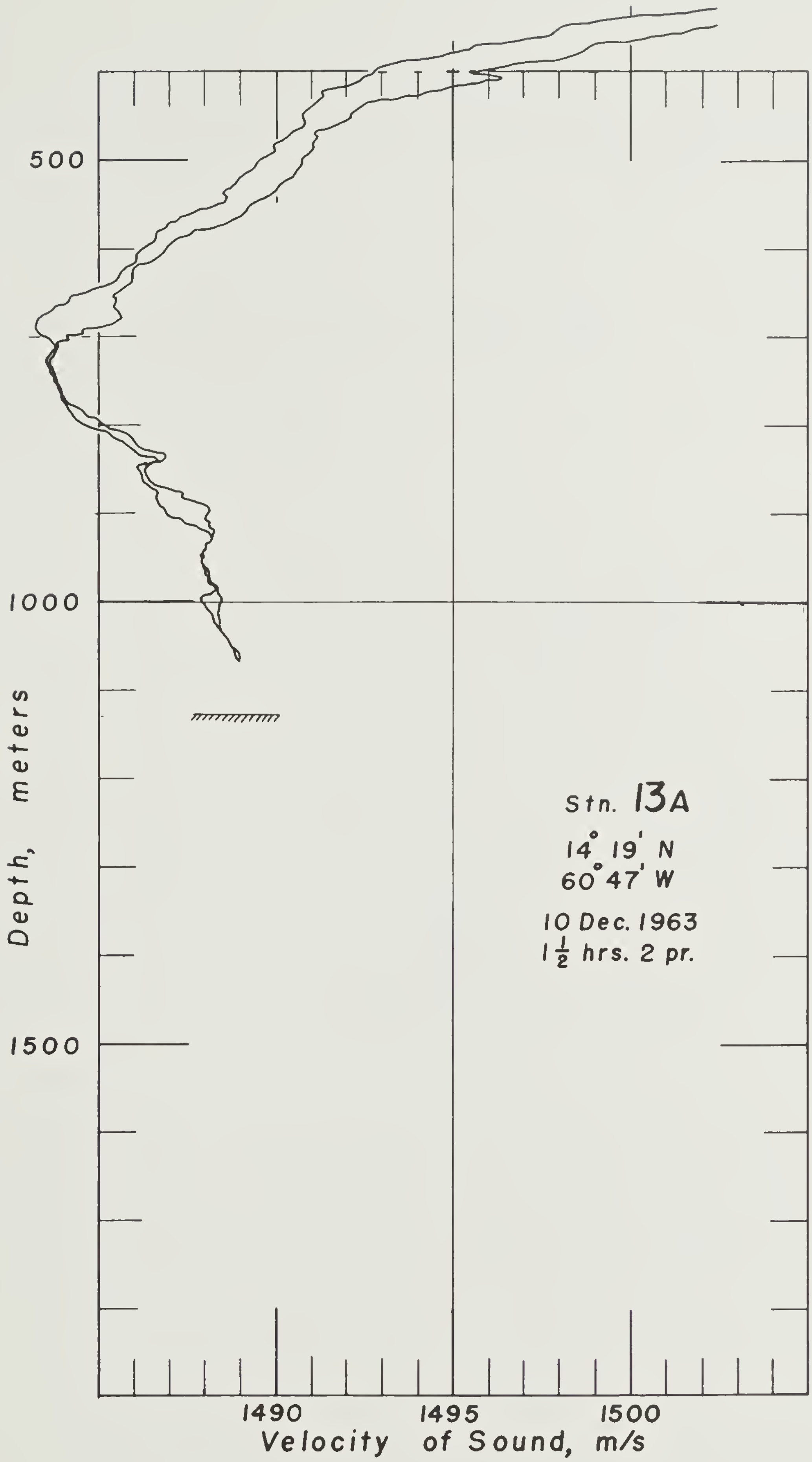

Fig. 36. Envelope of Profiles, Station 13a.

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Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Sound channel in ocean.						
Bermuda-Barbados Area.						
Sound velocity profiles, detailed.						
Sound velocimeter.						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

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There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

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Unclassified

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